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1930-1931.

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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

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Members whose subscription is not in arrear receive the Journal free of cost, and additional copies are charged at the rate of 7s. 6d. per part, unless otherwise stated. A member whose subscription is not paid by March 31st of the year for which it is due is considered to be in arrear.

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A medal and a prize of five guineas is awarded annually by the Council to that Student Member of the Institution who shall, in their opinion, have presented the best paper during the session.

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Advertisements. Advertisements are inserted in the Journal, and information as to terms, etc., can be obtained from Mr. Thomas Tofts, 301-302, Bank Chambers, 329, High Holborn, W.C. 1. (Telephone No. Hol. 4776.)

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that members send information regarding their movements to the Secretary, for insertion under this heading.

Mr. K. A. CAMPBELL is in England.
Mr. M. D. G. CAMPBELL is home from Persia.
Mr. D. H. CARTER has left for Mexico.
Mr. CHARLES DABELL is in Venezuela.
Mr. HAROLD DABELL is home from Egypt.
Mr. G. C. K. DUNSTERVILLE has left Egypt and is in Holland.
Lieut. G. C. FLOWER is in Mexico.
Mr. L. V. A. FOWLE is returning from Iraq.
Mr. J. O. GUTHRIE has left for Ohio, U.S.A.
Mr. W. R. S. HENDERSON is on his way to Burma.
Mr. H. R. HOSE is in Venezuela.
Mr. J. H. ROBERTSON is returning from Burma.
Mr. R. WOOD SMITH is home from Assam.
Mr. CYRIL THOMAS is on his way home from Assam.
Mr. L. A. TOONE is home from Sarawak.
Mr. E. E. UPTON is in Iraq.
Mr. F. WALMSLEY is home from Germany.
Mr. JACK WATSON has left Assam and is in Burma.
Mr. H. TEMPLE WATTS has returned from Papua.
Mr. G. E. WHEELER is on a short trip to U.S.A.
Mr. L. J. WILMOTT is returning to Burma.
Mr. C. C. WILSON has gone to Ecuador.
Mr. W. RAYMUND YOUNG is in Rumania.

The Secretary will be glad to receive information as to the whereabouts of the following members :—C. A. BAUDUIN, A. E. O. COOKE, E. DAWIDSON, J. C. FORTUNE, A. F. H. GEE, T. S. HARRINGTON, W. J. HARRIS, L. B. HOLLOWAY, A. W. IBBETT, H. F. MOON, A. F. C. PARKER, NAND LAL PASI, W. E. SHEPERD, D. S. TREBLE, R. K. VAN SICKLE and F. E. G. WATSON.

NOMINATIONS FOR MEMBERSHIP OF THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

The following have been nominated for membership of the Institution of Petroleum Technologists and their Application Forms may be seen at the Offices of the Institution :—

As Members.—Robert Allan, Louis Alfred Bushe.

As Associate Members.—Almon Lee Beall, Harry Dobson, Raymond William Dunster, Max Metsch, Donald Gray Phelps, Terence Charles Richards.

Transfer to Associate Members.—William Edmund Madden, Ian McCallum.

As Students.—Herbert Harland, Robert Edgar Moore.

As Associates.—William Henry Bailey, George John Hancock.

GERMAN BUNSEN SOCIETY.

The Thirty-fifth General Meeting of the German Bunsen Society (Deutsche Bunsen-Gesellschaft) for experimental physical chemistry will be held at Heidelberg, near the Rhine River, from May 28th to June 1st, 1930. "Spectroscopy and Formation of Molecules" will be the subject under discussion, and those desiring to participate should communicate with "Ortsausschuss der Deutschen Bunsen-Gesellschaft, Heidelberg, Ploeck 55," the local committee, which will also find accommodation.

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The complete index to the first ten volumes of the Journal of the Institution contains some 10,000 references to subjects and localities.

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A brief survey of the Technology of Petroleum based upon a Course of Lectures given by Members of the Institution of Petroleum Technologists at the Petroleum Exhibition, Crystal Palace, 1920.

This work will be found of value to students and those desirous of obtaining an elementary knowledge of the Technology of Petroleum.

A few remaining copies for disposal at 2s. 6d.

All the above to be obtained from the office of the Institution,

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THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND TWENTY-FIFTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, London, on Tuesday, February 11th, 1930, the President, Dr. A. E. Dunstan, occupying the Chair.

The Secretary announced that the members elected and the persons nominated for election since the last General Meeting were :—

The following gentlemen have been elected :—

As Members.—Bert Charles Frichot, Philip Morley Griffiths, Walter James Perelis, Claude William Burt Shorto.

As Transfer to Member.—Gwyn Elias, Henry Stuart Tegner.

As Associate Members.—William Parkinson Hirst, John Campbell Wright Robb, Stanley Lashmore Roberts, George Vernon Tullett.

As Students.—Henry Cecil Hastings Darley, Michael Everitt Kelly, James Francis Alexander Stark, Thomas Charles Gordon Thorpe.

As Associate.—Reginald Frank Alfred Baldwin.

At the Council Meeting held on January 14th, 1930, the following were nominated :—

As Members.—Donald Charles Broome, William John Burchett, Douglas Harold Jackson, Arthur Whittaker Richardson.

As Transfer to Member.—Henry Frederick Moon.

As Associate Members.—Henry Norman Bassett, John Howard-Glossop Goodfellow.

As Transfer to Associate Member.—David Glynn Jones.

As Students.—Reginald Charles Rogers, Herbert William Harry Wilkinson.

At the Council Meeting held on February 11th, 1930, the following were nominated :—

As Transfer to Member.—Douglas Leonard Alexander, Eric James Dunstan.

As Associate Members.—William Duff, Edward Vernon Wharton.

As Transfer to Associate Member.—Hendrik Willem Slotboom.

As Students.—Jack William Clack, Samuel Elliman, Kenneth Byrne Lanyon.

The President said that he was particularly asked to announce that the Annual General Meeting would be held at the Royal Society of Arts on Thursday, March 20th, 1930, at 5.30 p.m. On

that occasion a resolution would be brought before the meeting authorising the Council to proceed with the presentation of the appeal to His Majesty's Privy Council for the grant of a Royal Charter.

It was unnecessary for him to introduce to the meeting their friend, Mr. E. H. Cunningham Craig, whose eminence as a geologist was only equalled by his long and excellent service to the Institution.

The following paper was then read :—

The Oilfields of Alberta.

By E. H. Cunningham Craig, B.A., F.R.S.E., F.G.S., (Member).

On a former occasion, early in 1915, the writer had the privilege of putting before this Institution the results of his field work and studies in Alberta, under the heading of the "Prospective Oilfields of Western Canada." Now, after an interval of fifteen years, it is possible to be somewhat more precise, and to speak definitely of the "Oilfields of Alberta." In this interval of fifteen years much water has run under the bridges, and, especially lately, much oil has run into tanks and been piped to refineries, but, unless indications are entirely deceptive, all that has been achieved so far in the way of successful results will be eclipsed before very long by the results still to be obtained when a series of well-considered tests of new ground and newly discovered structures has been made.

During the War, and for some years after it, very little development work was done, and such partially successful results as were obtained were neither remarkable nor specially profitable, but the good people of Alberta, who had put their energy and their capital into the petroleum industry, never lost heart, but continued, as and when possible, to prosecute their search for oil, undeterred by an almost complete lack of help, and even sympathy, from this country.

Meanwhile as time went on drilling methods have been vastly improved—a three thousand foot well is now looked upon as comparatively shallow and a five thousand foot well as nothing unusual—the outlook, or one might say the downlook, of the oil operator has been enormously extended, fresh worlds to conquer have been disclosed and are now in the process of being conquered. The vision of the prospecting geologist has been correspondingly enlarged, and the writer personally must admit that developments of which he had formerly only a dim and faint idea have now become within the range of practical proof.

It was the drilling in of the No. 4 well of the Royalite Company in Turner Valley that first made it clear to the scientific and industrial world that that now famous anticline was destined to be a paying oilfield. Other strikes of filtered oils and wet gas had been made before, but nothing comparable to that of Royalite No. 4, which, in spite of one or two chokings for brief periods, has kept up, and even increased, its initial flow of wet gas, and after five years is still yielding more than 500 barrels of light gasoline per day. The success of this well was the cause of much activity in the neighbourhood—several other wells were brought into production, and the productive field was proved for some distance, both to north and south.

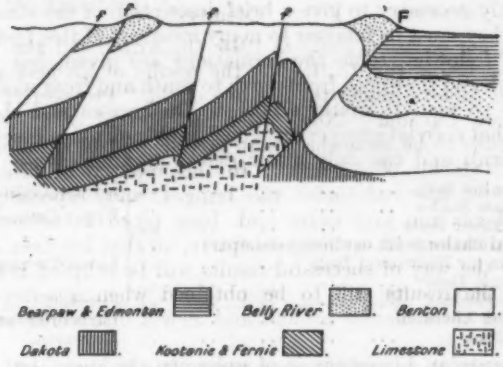


FIG. 1.

DIAGRAMMATIC SECTION ACROSS TURNER VALLEY.

The strike of wet gas made in July, 1928, in Home No. 1, on a site three miles to the southward of the producing area, served to extend the field still further. This is considered up to date the best locality in the field, and it has been followed by a number of other wells, so that a productive area fifteen miles long has been proved.

Development of other areas outside the Turner Valley has been slower and less satisfactory, and has unfortunately been confined to very few localities—*e.g.*, Wainwright, where heavy oil is obtained at a comparatively shallow depth.

There has been, however, in the last three years, much prospecting of new territory, with the result that many promising geological structures have been discovered: some are being tested now, and others will soon be put to the test.

The work of the Geological Survey has contributed largely to our knowledge of geological conditions, though, as the area to be examined is of enormous extent, the work has often had to be done on a small-scale map, and many gaps have still to be filled in.

General Geology.

A brief review of the geological conditions is necessary in order that the problems to be solved may be clearly understood. Though no very important new discoveries have been made in connection with the stratigraphy, many significant details have come to light, while well records have supplied much information regarding the thickness and variations of different groups of strata.

It is only necessary to give a brief description of the strata dealt with, as they must be familiar to many members of this Institution.

In the following table the formations are given, but it must be remembered that both from north to south and from west to east there are so many variations both in thicknesses and characters of beds, that correlation over any considerable distance is sometimes very difficult and can only attempted approximately :—

Edmonton Beds	Eocene-Cretaceous.
Bearpaw Shales	Upper Cretaceous.
Belly River Beds	Upper Cretaceous.
Benton Shales (with cardium sandstone)	Lower Cretaceous
Dakota (or Blairmore) Beds	Lower Cretaceous
Kootanie Beds	Lower Cretaceous
Fernie Shales	Jurassic.
Madison Limestone	Carboniferous.
Limestone	Devonian.

The Devonian Limestone is of unknown thickness, but it must amount to several thousand feet in the Rocky Mountains. It is covered conformably by a similar limestone, identified as of Carboniferous age, which, however, does not seem always to be present. It is known in Montana as the Madison limestone, and reaches about 1000 ft. in thickness. Thin chert bands are frequent in the upper part of this limestone, and two zones of partial dolomitisation have been identified, one at about 200 ft. and one at 800 ft. from the top. This dolomitisation renders the limestone slightly more porous, and thus it becomes under favourable conditions an effective reservoir for wet gas, or rather for a very volatile liquid, which on release of pressure takes the gaseous form with great rapidity. All the limestone locally contains gas, but it is only from the dolomitised zones that it is disengaged rapidly enough to give good productions. The age of the dolomitisation is not known, but there is evidence pointing to its being pre-Jurassic. There is also evidence indicating that towards the west ; *i.e.*, in the Rocky Mountains, the dolomitisation increases in the upper beds of the limestone. It will be

noticed that there is a great gap in the geological sequence, representing a vast interval of time, between the top of the limestone and the base of the Jurassic. In some parts of the Rocky Mountains Triassic strata are exposed, so there is a probability that there has been much denudation of intermediate formations before the Fernie shales were deposited. It is possible that conditions of desiccation existed which could have caused the dolomitisation of the limestone in zones where aragonite was prominent. The salt springs on the Athabasca River and salt beds in north-eastern Saskatchewan may be traces of a former basin, or basins, of desiccation.

Just above the limestone a bed of chert conglomerate has been encountered in wells, indicating considerable denudation of the upper beds of the limestone.

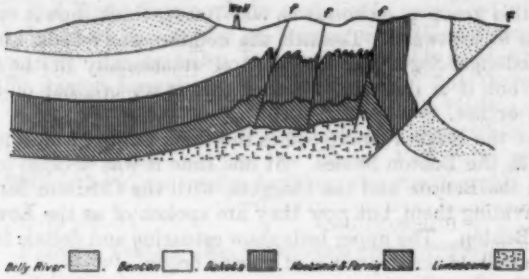


FIG. 2.

DIAGRAMMATIC SECTION ACROSS ELBOW RIVER VALLEY.

The Fernie shales are an important group, though less than 500ft. thick in the Foothills, a very meagre representative of the Jurassic formation. They are mostly dark shales, but contain one well-marked oil zone near the middle, known as the Dalhousie Sands. Beneath this glauconitic sands, dark shales and a band characterised by Belemnites, have been recognised in wells in the Turner Valley, and are good "markers" for drilling purposes. A band close above the limestone is known to the drillers as the "poker-chip shales."

The junction between Fernie and Kootanie is not very well defined, and seems to be quite conformable.

The Kootanie or Kootenay Beds are of great importance, though only reaching a thickness of at most 400 ft. in the foothills area. At the top a thin coal seam usually occurs, and makes another good marker. Beneath this comes a well-known oil horizon called the Home Sands, which have been encountered in many wells. Red

or even maroon and green mudstones, indicating terrestrial conditions, are characteristic of the Kootanie Beds, while in the outcrops at the western margin of the foothills five or six coal seams may be observed. Still further west, in faulted inliers in the Rocky Mountains, the Kootanie Beds open out into a very thick arenaceous group with many workable coal seams, chiefly anthracitic.

Above the Kootanie Group, the Dakota or Blairmore Group is ushered in by a grit or conglomerate. This in the foothill outcrops may be a torrential conglomerate with huge waterworn boulders, indicating a considerable amount of local denudation of the Kootanie Beds, but in the Turner Valley it may be represented merely by a gritty band. The group consists of calcareous sandstones, shales, and thin argillaceous limestones, the sandy phase predominating, but with few really porous sands. In the Turner Valley this group is reckoned as 600–700 ft. thick, but it certainly thickens to westward. Towards the middle, sandy beds, known as the Macdougal-Segur Sands, yield oil occasionally in the Turner Valley, but it is doubtful whether this is an original oil-bearing horizon or not.

Above the Dakota Group comes the thick group of marine shales known as the Benton Shales. At one time it was divided into two groups, the Benton and the Claggett, with the Cardium Sandstone Beds dividing them, but now they are spoken of as the Lower and Upper Benton. The upper beds show estuarine and deltaic features, but the bulk of the deposit is of marine origin.

The Cardium Sandstone consists of two or three separate bands of conglomerate, consisting of well-rounded pebbles of quartz and chert in a calcareous sandy matrix with many fragments of Cardium. These bands are not persistent over the whole foothills area, but are usually represented and make good markers.

Above the Benton come the Belly River Beds, a strong sandstone group with coal seams. This group usually forms well-marked lines of hills enclosing valleys of the Benton Shales. The coals do not extend everywhere in the formation, but are worked in many localities. No oil is recorded from the formation, but gas has been struck, sometimes in great quantity, in many localities.

Above the Belly River Beds the Bearpaw Shales, an estuarine to marine group, are recognised, especially in the prairies and in Southern Alberta, but in some localities have been either never deposited, or cut out by unconformity at the base of the Edmonton Group. The latter group is a thick group of sandstones and shales, with lignites or semi-lignites, a typical deltaic phase with well-differentiated beds, sometimes richly fossiliferous. No oil has been recorded from the group, but gas has been struck in shallow wells in the prairies.

The above descriptions apply chiefly to the foothills area near Calgary, and Mr. Madgwick's vertical section has been followed, with some slight modifications.

The variations in the Cretaceous formation are remarkable. To begin with, in the Calgary district there is a regular thinning out from west to east; in a distance of fifteen miles the series from Belly River Beds to Fernie Shales loses half its thickness, though, as Mr. T. G. Madgwick and others have shown, it is still possible to make correlations.

In the north the Kootanie Beds are represented by the Athabasca Tar Sands, asphaltic sands which attain a thickness of 200 ft., and are covered by the Clear-water shales which represent the Dakota and Benton Groups.

In Montana (Kevin-Sunburst field) and the south of Alberta the Dalhousie and Home Sands can be tentatively correlated with the Ellis and Sunburst Sands, and oil-bearing conditions extend over a wide area from the foothills. It is hardly possible to correlate all the locally named formations of different areas, but the general position in the series is usually sufficient to enable fairly accurate stratigraphical relations to be determined. In areas where much drilling has been done—*e.g.*, in the Turner Valley—in spite of steeply dipping beds and strike faulting, the stratigraphy is well established.

Proved Fields and Unproved Structures.

The definite achievements of petroleum exploration in Alberta are:—(1) The establishing of the Turner Valley field as a prolific producer of wet gas, from which a light petrol is easily obtained in paying quantity by means of separators; (2) the proving of the Wainwright field as a producer of heavy oil in small quantity. These may seem somewhat inadequate results, considering the time and money that have been spent in exploration, but in reality much more has been done, and many other areas have been partially tested with sufficient success to point to the probability of there being several new oilfields with excellent prospects.

The Turner Valley Field.

This field, so far as the writer is aware, is unique in the world as regards conditions. Every well drilled to sufficient depth in the limestone within a certain easily defined area upon the anticlinal structure has obtained a flow of wet gas sufficient to yield a paying quantity of light gasoline. The yields from different wells vary according to their position upon the structure, and according to the porosity of the dolomitised bands in the limestone,

the porosity naturally varying to some extent from one locality to another. A gas flow of eighteen million cubic feet per day is sufficient to give a yield of four or five hundred barrels of light gasoline or, as it is called locally, crude naphtha. The gas is run through separators in which, under the intensely low temperature due to the expansion of the gas and the great pressure, which amounts to as much as 2,000 lbs. per square inch, the gasoline is condensed. No attempt to bubble the gas through absorbent oil, and thus collect the full gasoline content, has yet been made, and the slightly smoky flame of the waste gas which is burnt in the open proves that a greater percentage of gasoline might be obtained. At present the waste gas is being supplied to every drilling well in the valley, and also supplied to Calgary by pipe line, but there is, nevertheless, a loss of anything between a hundred and fifty to two hundred million cubic feet of gas wasted every day. This gas is burnt in open flares at some distance from the producing wells, and this waste is the object of considerable anxiety to the Provincial and Federal Governments. It is suggested that exportation of the gas by pipe-line may be resorted to. The glare from the burning of this waste gas can be seen at a distance of fifty miles from the field at night. It is an excellent "sky-sign" as an advertisement of the productivity of the Turner Valley, but is a most regrettable instance of waste of cheap power.

The Turner Valley has been proved productive over a distance of twelve or fifteen miles. Its limits, to north and south, have not yet been proved, but from east to west the productive area is already well defined, varying between one and one and a-half miles.

Apart from the wet gas from the limestone, productions of crude oil are obtained from a number of wells, almost all of which are on the western flank of the structure. This crude oil is in most cases naturally filtered, and the specific gravity varies according to the position on the structure and the thickness of strata through which the oil has migrated. Strike faults have enabled such migration to take place across the bedding, and the result is that oils of many different specific gravities have been obtained and are being produced.

The structure is at best a narrow anticline defined on both sides by strike faults, which hade invariably to the westward at high angles. The accompanying cross section gives a rough idea of the structure, but it cannot be pretended that it is a true cross section of any part of the fold, for there are many local variations, and detailed correlation has not yet been carried out in sufficient detail to give a really accurate representation of the structure.

There are at present forty wells producing, thirty-three of which are producing crude gasoline from the limestone, while nineteen

others are producing crude oil of various grades. Some wells are producing both. Fourteen wells at present drilling are in the limestone, with good hopes of production, and a number of other wells are drilling. The total production from the field up to the latest information is approximately 3,080 barrels per day of crude gasoline from nineteen wells, and approximately 763 barrels per day of light crude oil from nineteen wells. These figures vary from week to week, and may now be considerably larger through new wells coming in. The writer must admit that he has never given much attention to this field, and beyond locating one well, in 1914, which, after the land had changed hands twice, has now been drilled, and is known as Home Oil Co. No. 3, has never made a location in the field. The well known as Merland No. 1, which has lately been brought in, has extended the production area by approximately three miles, and has indicated that the production area may still extend for one or two miles further to the southward.

Wainwright Field.

The Wainwright field is situated out on the prairies to the eastward of the great syncline east of the foothills, and upon the gentle anticlinal rise which has been traced in a great curve from the international boundary to within a short distance of Edmonton. This gentle anticlinal bend brings up strata of the Belly River group, and a number of attempts have been made to strike oil upon local very gentle domes on this general structure. In the Wainwright neighbourhood a number of wells have been drilled, the best of which gives a production of approximately 100 barrels per day of heavy oil, accompanied by strong gas. The Cretaceous Series along this structure has thinned out in many localities to little more than 2,000 feet, and the oil-bearing bands which occur at the base of it are thin as a rule. The structures in all cases are so gentle that no great concentration of oil can have taken place, and the oils are more of the nature of inspissated residuals than of light crude oil. It is probable that in certain localities on this broad general structure better results may yet be obtained, but so far as the ground has been tested up to the present, only heavy oils in small quantities have been proved.

Oilfields Still to be Proved.

The most recent field work that has given promising results has been almost entirely in the southern part of the area, near the International boundary. The Kevin-Sunburst field in Montana, a gentle fold pitching north-westward, has attracted much attention during recent years, and it has been found that there are several

local structures orientated in much the same direction across the Canadian border. One of these, a small dome, has been successfully drilled by the Vanalta Company, and a production amounting to at least 70 barrels per day has been obtained at the comparatively shallow depth of about 2,400 feet, the oil being of 0·85 sp.gr. This well has been the cause of considerable activity in the neighbourhood. Several somewhat similar structures remain to be developed, with excellent prospects of good, if not large, productions. Deeper drilling, however, may result in better productions being obtained.

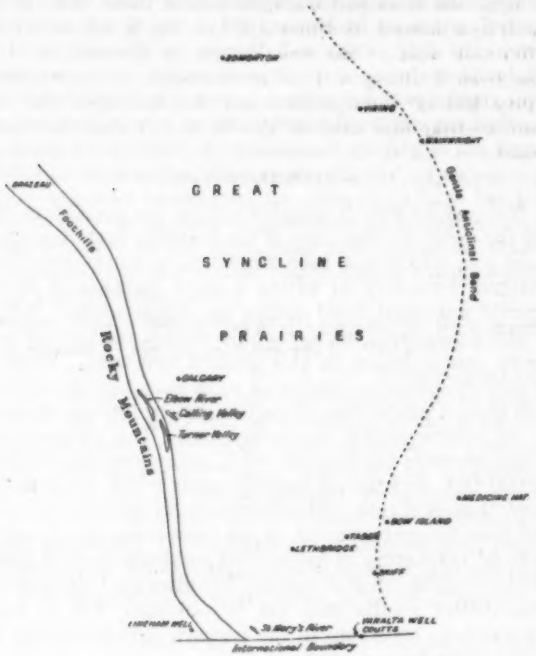


FIG. 3.

PART OF ALBERTA.

In the foothills ground, west of the strike of the Turner Valley, a number of wells are now being drilled, e.g., in the Waite Valley and in other small faulted structures west of the Turner Valley. Of such exploitations, many have been or are being drilled in very steeply dipping and faulted structures, where, if oil should

be struck, only very narrow areas of concentration could be tapped. There have been, and will be, many practical failures under such conditions. In the writer's opinion the most promising of these experimental wells is that of the Elbow Oil Company on the structure known as the Moose Mountain or Elbow River anticline. This is the structure which the British Alberta Oil Company attempted to test in 1914, but the well, which was drilled to 3,000 feet, was situated too near the crest of the flexure, and crossed a fault, entering practically vertical strata on the eastern flank of the structure, and thus failed to strike oil, though giving slight shows at intervals throughout a thickness of some 700 feet. The present well now being drilled by the Elbow Oil Company is situated some 1,700 feet west of the crest, where it is expected that no difficulties from faulting will be encountered. The structure in this locality has advantages over every other structure in this district on a strike-line west of the Turner Valley by having a fairly broad syncline to the westward, thus giving a concentration area twice or perhaps three times the breadth of that of the Turner Valley. Only one other well is being drilled at present upon this structure, and that, it is to be feared, lies too far to the eastward to give hope of commercial production. A commercial strike of oil on this structure, however, will prove a length of approximately seven miles along the flexure, with a probability of further wells to the northward, if properly located, proving another seven or eight miles. The breadth of the productive area, however, must in any event be narrow.

A number of other prospective fields have been mapped in the foothills area, some of which are in the south, about the latitude of the town of Lethbridge, while others lie north of Calgary, e.g., the Grease Creek and Brazeau areas. These structures are sharp and probably faulted. Oil shows are observed in outcrops to the westward.

Outside the foothills area as strictly defined, structures have been identified where dips on the flanks are comparatively gentle and where there seem to be good chances of striking oil in quantity, provided that a sufficient quantity of oil has migrated to the respective localities. Of these the most notable is what is known as the Calling Valley structure, a comparatively gentle elongated dome, the north-western end of which is within sixteen miles of Calgary. There are other smaller, but still favourable, structures found to the eastward, but still on the western flank of the great syncline. Two of these are being drilled at present, but their prospects are problematical, although, owing to the thinning out of the Cretaceous Series to the eastward, the drilling will be much shallower than might be anticipated.

In the southern ground, not far from the International boundary, there are structures just on the border of the foothills where the dips on the flank are sufficiently high to ensure a good concentration of any oil that may be beneath the surface. Such structures have not yet been tested, but have certainly got remarkably good prospects.

The writer does not pretend in this brief account of the prospective oilfields to have covered all the ground where oil may be struck in commercial quantity. There are two wells now abandoned in the neighbourhood of Skiff where oil is seeping slowly from the top of the casing, and there are many other areas on the prairies, e.g., near Taber and Suffield, where oil has been encountered in wells, but where commercial production has not yet been conclusively proved. It will be seen, however, from the above brief notes, that there are very large areas in which favourable geological structures may be delineated, and a few in which the structures are so well defined as to justify immediate drilling. The writer has little doubt that of these a certain number have every prospect of showing successful results.

Source of the Oil.

Apart from the difficulty of elucidating faulted and thrust structures in the foothills, the only interesting scientific problem, and the one which should be of most interest to the members of this Institution, is the source of the oil.

There are two rival theories, and each seems to have numerous supporters. These are (1) that the oil is of Palæozoic age, indigenous to the Madison and Devonian Limestones, or to some older strata yet unreached by the drill, (2) that the oil is of Mesozoic age, indigenous to the Lower Cretaceous, and possibly to the Fernie Shales (Jurassic).

The problem is of great importance, since, according to which theory is followed, the best results from drilling will be sought for in widely separated localities and under different conditions of structure, while estimates of the depth to be drilled in each case will also be affected.

For the first mentioned theory there is a certain amount of *prima facie* evidence. Devonian strata are productive in many American fields, though probably under completely different geological conditions, and in the case of Alberta nearly two-thirds of the production in the Turner Valley is from the limestone of Carboniferous and Devonian age.

South of the International border also the Kevin-Sunburst field has given very good production from dolomitised zones in these limestones. Even on the Athabasca River in the north

wells drilled through or below the horizon of the tar-sands have encountered shows of light oil in the Devonian limestone. Also where the tar-sands have been removed by denudation and the limestone laid bare, heavy oil residues are sometimes found in the joints of the calcareous rock.

Possibly to some extent the theory has found favour owing to the very prevalent idea, or one might say delusion, among many oil men that oil always tends to rise towards the surface through no matter what thickness of strata. It is suggested, therefore, that the oil, originating in the Carboniferous and Devonian limestone, or from some strata of greater age, has found its way upwards as a light oil or wet gas, and has condensed into heavier oil in the overlying Jurassic and Cretaceous rocks. This suggestion has even been made in connection with the tar-sands of Athabasca, which spread over some 10,000 square miles, lying horizontally upon a denuded surface of the limestone.

There is also the ancient and respectable theory that oil is formed from the remains of marine organisms, the hard parts of which, either as distinct fossils or as comminuted debris, build up such calcareous deposits. This theory is still extant, although it has never been shown how it is possible for the soft parts of such animal organisms to survive the death of the organism and become entombed and buried deeply enough to be formed by a selective sea-change into petroleum.

Against the theory of Palæozoic origin, however, there are well known facts that require explanation.

To begin with, how is it that in Alberta oil or wet gas is never found in the limestones except where they are covered by Mesozoic strata, or at least in localities where Mesozoic strata have only recently been removed by denudation? How is it that, even where these limestones are thrown into large and well defined anticlinal structures, no concentration of petroleum, nor even traces of it, are found in outcrops near the crests? Even at Fort Norman, where the late Dr. Bosworth showed great anticlines in the limestone, the oil was only found on the flank where Cretaceous strata are piled upon it. It was in the Cretaceous strata that the oil was struck.

Then there is the question, even more difficult to answer, if the oil was formed in Carboniferous, Devonian, or earlier times, what happened to it in the interval, amounting to geological periods, during which these limestones were flexured and exposed to denudation? The Permian, Triassic and the greater part of the Jurassic periods taken together represent an enormous lapse of time. How did the petroleum (very light petroleum) exist during this lengthy period, only to appear later after a great mass of

sediment had been deposited upon it? Furthermore, we know that during this interval there was a period of denudation. The mass of Triassic sediments that are known in the Rocky Mountains in Southern Alberta have all been removed and the surface of the limestone is waterworn and denuded. During this interval we may be fairly certain that the dolomitisation of certain zones in the limestone took place, the zones that are now productive reservoirs of oil and wet gas. Though we do not know everything

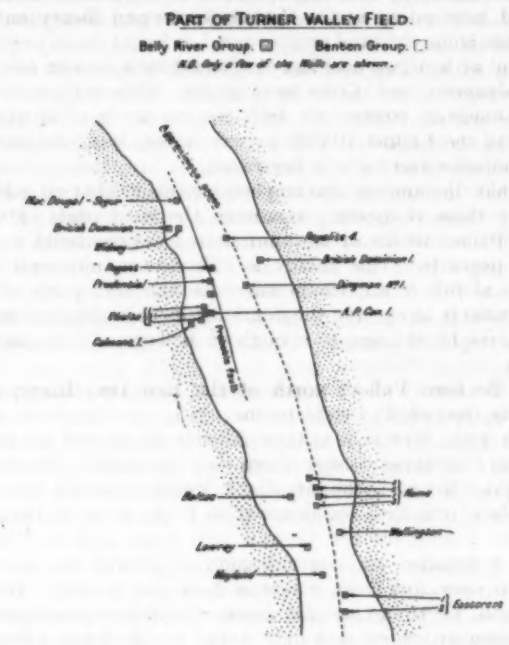


FIG. 4.

about the process of dolomitisation, it has been proved that magnesium-bearing waters acting upon a bed of limestone cause dolomitisation to take place to a greater or less extent, the zones richest in aragonite being most readily attacked. The circulation of magnesian waters, therefore, must have been in evidence during this interval, and it is the effect of this circulation that has prepared the reservoirs that now in certain localities hold oil and gas.

Where was the oil during this age of dolomitisation? In the Rocky Mountains we find exposed zones in the limestone really well dolomitised, cavernous and far more porous than in wells drilled in the Turner Valley, but containing no traces of petroleum. The inference is obvious, the oil must be of later origin than the dolomitisation, and is only present in the dolomitised zones because they form slightly more porous reservoirs than the rest of the massive calcareous group.

This leads naturally to a consideration of the theory of Mesozoic origin, and here we do not need to depend upon theory but upon innumerable facts.

To begin with, if we consider the localities and horizons where natural seepages of oil are to be observed, we find they are all in Lower Cretaceous strata. Commencing near the international boundary in the Blakiston Valley, well marked seepages are noted in the Kootanie and to a lesser extent in the Dakota beds. It was here that the famous Lineham well was drilled twenty odd years ago, where these oil-bearing strata in recumbent folds are overthrust by Palæozoic limestones and even older formations. There are no seepages from the limestones, but the porous sands of the Kootanie are full of oil, which has been tapped in shallow wells of 800 to 1000 ft. deep, and green fluorescent oil can still be bailed up from a depth of some 6 ft. in the Lineham well, as the writer can testify.

In the Brazeau Valley, north of the Red Deer River, similar seepages are recorded; while to the north-east the great outcrop of the Athabasca Tarsands is an excellent testimony to the petroliferous nature of these Lower Cretaceous horizons. Even as far north as Fort Norman, the late Dr. Bosworth has shown that the lowest beds of the Cretaceous are oil-bearing, while the limestone is barren.

Taking a broader view of the general geology, it is obvious that to the westward there was a land surface in early Cretaceous times, proved by the great coal seams of the Kootanie formation; passing eastward there is ample evidence of deltaic formations thrusting out into the shallow sea to the eastward. Numerous rivers spread their deltas, the greatest being in the north, as evidenced by the tarsands; a branch of this great delta turned south-eastward, and accounts for the Wainwright field, but in the south also deltaic deposits are conspicuous, and extend far into what is now the prairie country. In the neighbourhood of the Turner Valley and the Elbow River the delta of a minor river can be traced. And all these deltas in and east of the foothills are characterised by the petroliferous, not the carbonaceous phase. It is true that the formations thin out rapidly in the eastward

direction, arenaceous deposits intercalating with a more marine type of sediment, but the oil-bearing nature of these Lower Cretaceous horizons persists for a distance of 50 miles, and wherever gentle dome structures have been developed and tested oil has been proved in greater or lesser quantity. Gas-sands extend, as is so often the case, beyond the region of oilsands, and the gas productions of the Bow Island, Viking and Wainwright fields are all obtained from Lower Cretaceous beds.

So far the case is perfectly simple and in accordance with known and well understood conditions in oilfield territory in many parts of the world, but there still remains the explanation of the remarkable profusion of oil shows of different specific gravities encountered in wells in the Turner Valley and elsewhere in the Calgary district.

Taking a broad view of all the data, the explanation is also quite simple, and has indeed been given by the writer in several publications.

Owing to the rapid thinning out of the Kootanie group from west to east, it does not contain in the foothill country sufficient porous rock in its 300 to 400 ft. of total thickness to contain more than a small portion of the petroleum that has been formed. Many thick deposits of vegetable matter, the remains of which are represented in the western outcrops as anthracitic coal, have been entombed in the Kootanie group in the foothills under such conditions of sealing and pressure most favourable to the formation of petroleum, and, as the petroleum forming stage has been reached, have naturally collapsed, leaving the oil to seek a porous reservoir to impregnate. It may be considered that this view is somewhat theoretical, but it is in accordance with data gleaned from many different parts of the world. As the writer has shown, till the jetonised state has been reached and passed in a vegetable deposit, it is possible under favourable conditions to transform the vegetable matter into petroleum. There is a prevalent idea that oil is formed from vegetable debris in argillaceous strata, but the same is true of thick deposits of vegetable matter in arenaceous environment when securely sealed by impervious rocks above and subjected to sufficient pressure. The very topmost bed of the Kootanie group in the foothills is frequently a partly formed coal, but of the numerous lower seams of coal there is no trace : they are represented by petroleum.

But in the thinned out Kootanie Group there is not a sufficient thickness of porous sandstone to contain any great quantity of petroleum, and in consequence the liquid hydrocarbons have been forced under enormous pressures to migrate. This migration has taken place in every direction—upwards, downwards and laterally.

And during this migration through great thicknesses of strata of, at the best, minute porosity, filtration of the crude petroleum has naturally ensued. A study of the shows and productions of crude oil in Turner Valley wells makes this very clear. The writer has not found it possible to obtain data of all such occurrences of oil, but has collected sufficient evidence to prove beyond doubt that such natural filtration has taken place.

Generally speaking, all the crude oil shows are found on the western flank of the flexure, and the specific gravity of the oil decreases eastward, indicating that the migration has been from west to east. Thus the famous Dingman well, the first productive well on the structure, yielded from two horizons of very slightly porous rock in the Dakotas oil of 64 and 55 Beaumé gravity (specific gravity 0·75 and 0·72), the upper show being the lighter.

One of the most interesting wells of which a record is available is Calmont Oil Company's No. 1, which is situated on the western flank more than one mile from the presumed crest of the flexure.

This well reached the Dakota formation at 3,984 ft., where a good showing of oil estimated at 25 to 30 barrels per day was struck. The oil is of 0·84 specific gravity, and resembles the oil struck in Moose Mountain Oil Company's well in 1914 on the Elbow River anticline. It is a brown oil, partially filtered.

At 5,363 ft. in the Kootanie Group the Calmont well struck an oil of about 0·87 specific gravity, with strong green fluorescence. At 5,463 ft. in the Fernie Group (Jurassic) a clear brown oil of 0·77 specific gravity was encountered, and at a slightly greater depth a similar oil of the same gravity at the base of the Fernies, just above the contact with the limestone. Neither of these oils shows fluorescence. In the limestone a highly filtered straw-coloured oil of 0·68 specific gravity was struck. Here we have evidence of filtration both upwards and downwards, the fluorescence due to solid particles in the colloidal solution being naturally the first natural characteristic to be removed by filtration. The oil from the 5,363 level seems to be the parent oil.

Similar—though not so complete—evidence is obtained from a number of wells. The Macdougal-Segur in Section 12 on the western flank struck an oil of about 0·86 specific gravity in the Dakotas. The Widney Well No. 1, 600 yards to the south, but slightly farther from the crest, struck oil of 0·86 specific gravity at 3,110 and 3,180 ft., also in the Dakotas, and is giving a production of approximately 100 barrels per day. Nearly a mile to the south-east, but nearer the crest, the Prudential Oil and Gas Company is pumping 40 barrels per day of 0·83 sp. gr. oil from 2,774 ft. Okalta No. 3 well in Section 1, close to the Prudential Well, but farther from the crest, has a heavy green oil at 2,430 ft. All these

oils are apparently from Dakota strata, but have probably migrated across a fault, and are only slightly filtered.

Okalta No. 2 has an oil of 0·77 sp. gr. from the Fernies. This is probably the same oil struck by the Calmont No. 1 at 5,463 ft., the difference in depth being due to the respective distances from the crest. Okalta No. 1, between No. 2 and Calmont No. 1, has been drilled down into the limestone, and is producing " crude naphtha " of 0·69 sp. gr. from the gas flow.

Approaching nearer to the crest, crude oils are less conspicuous. Regent No. 1 in the north-east corner of Section 1 is producing from the limestone at 5,000 ft. odd a crude petrol of 0·65 sp. gr., the lightest known in the field. Very light filtered oils in wells on the eastern flank have been recorded at depths of 3,945, 3,890, 3,527, 3,685 and 3,640 ft., but productions are always small.

Going southward, the wells of the Home Oil Company have yielded further evidence, and the Home oil sand of the Kootanie takes its name from the Company. The production of crude petrol from the limestone is greater in this section (Section 20, township 19, range 2) than in any other part of the field, and a number of different companies are drilling in the vicinity.

Farther south there are many wells drilling, and some have reached the limestone with every prospect of being productive, but in the haste to reach the limestone it is to be feared that many light shows of oil, which would furnish interesting evidence of the migration and filtration of the petroleum, have been disregarded.

The newly brought in Merland well, the most southerly in the field, is situated on the eastern flank, and is probably not tapping the limestone directly, but is getting its gas (fourteen million cubic feet per day), through a fault. The gravity of the naphtha produced is given from two different sources as 0·673 and 0·669. The well has only reached to the base of the Dalhousie sand.

It is to be noted that the same horizons that furnish these comparatively light oils from the Kootanie and Fernie beds yield oil of 0·94 sp.gr. in the Wainwright field, a crude oil of little better quality in the Skiff district, and in the Vanalta well near the International boundary a good fluorescent parent crude oil of 0·85 sp.gr.

Reviewing all the evidence, there can be little or no doubt of the migration and filtration: the parent oil rocks are of Kootanie age, with some doubtful cases of Dakota or Fernie oil. The further the migration the more filtered the petroleum, where oil has been unable to penetrate wet gas has succeeded, finally almost dry gas has even reached the surface along lines of faulting in some localities in the foothills.

The limestones are only reservoirs of very volatile fluids or wet gas because their slightly dolomitised bands are sufficiently porous to serve as reservoirs. If localities can be discovered where the dolomitisation is more complete and thus affords more effective reservoirs, as for instance in the Kevin-Sunburst field, we may confidently expect good productions of more or less filtered crude oil.

Conclusions.

From this necessarily brief and somewhat sketchy account of the Alberta oilfields, it is evident that there is still room for much scientific exploration. It is generally admitted that the Turner Valley field, however much its production of crude petrol from the limestone may be increased, is not sufficient upon which to found a large and prosperous refining industry: it is merely a very large and important "show" of oil, pointing to the probability of more important fields.

Till recently the search for new fields has not been prosecuted with diligence.

Unfortunately the ground immediately west of the Turner Valley whence the oil seems to be coming is so cut up by strike faults all hading to the west that there is no hope of obtaining good productions. The Waite Valley, some six miles to the westward, is a structure of fair size, with two crestal areas, but it is bounded by similar reversed faults. Several wells are being drilled in that valley and promising shows of filtered oil have been encountered, but till a well reaches the limestone, the value of this structure cannot be estimated. It is possible that the limestone may show a higher stage of dolomitisation and porosity, in which case good productions may be looked for locally.

The Elbow River structure, though on the same line of strike as the western half of the Waite valley, is really in a different category, since there is no faulting to the west of it, but till a successful well has been drilled, this structure must be regarded as a prospect.

In the foothills area further south there are many favourable though not large structures worth testing as yet untouched, but possibly the gentler anticlines just outside the foothills afford the best chances. This applies also the ground in the south between Coutts and Cardston.

This year will undoubtedly see active development: there will be disappointments, successes and possibly some surprises. There are, it must be admitted, far too many small companies, and few of them are strong financially. There are also a few larger companies which control great acreages of land, much of which

is obviously useless; the craze for large acreage rather than carefully selected ground is still prevalent. Companies have been formed with 20 to 30 acres of safe productive land in the Turner Valley, bought at fabulous prices, and a few scattered and very doubtful areas in different localities.

Pure wildcatting is still in evidence here and there. But the reward of success is great; a single good well in the Turner Valley may make a company prosperous as long as the production lasts. And this at least may be said for that remarkable field, there is very little sign of diminution in the gas-flow, even after four or five years.

It is unfortunate, both for Alberta and for this country, that very little British capital so far has been employed in prospecting for and testing new fields. It would be very difficult now for a British Company to acquire large interests in the most promising areas without paying very high prices for land. Though many European geologists have spent months in examination of areas of promise, the chance of acquiring them seems in most cases to have been lost.

What is really required is a few large and well-organised companies, managed in Canada by men with local knowledge, but supported financially from Britain, it being postulated that only land carefully selected should be tested.

It is a matter of importance, not only for Alberta, not only for Canada, but for the Empire, that the petroleum resources of the Province should be developed scientifically, economically and quickly. There is no over-production in Canada, every gallon of oil or petrol that can be obtained is needed and is sure of a ready market. Though the modest prediction of the writer in his contribution on Petroleum Resources of the Empire to the Empire Congress of Mining and Metallurgy has already been exceeded more than threefold in the Turner Valley alone, the total production is still only about one million barrels per annum, and the import from the United States is still very large. It is not in the Empire's interests that the control of the new oilfields of Alberta should fall into alien hands: that is a danger that is fully realised by Canadians. There is great work to be done, and it is to be regretted that the Mother Country is taking so little part in it.

DISCUSSION.

The President said that the Institution was honoured by the presence of a number of eminent geologists. It had always been his experience that of all controversialists geologists were

by far the best. He therefore did not propose to interpose any remarks of his own between the distinguished author of the paper and his commentators.

Mr. A. Beeby Thompson said that the Institution was indebted to Mr. Cunningham Craig for putting forward recent facts relating to the development of the Alberta oilfields, and as there were in the paper so many points raising controversial matters he felt sure there were many present who would wish to take part in the discussion. There were, indeed, certain features connected with the Alberta oilfields which were very unusual and very puzzling. Firstly, he thought there was no field in the world which presented quite the same characteristics as that of the Turner Valley. The only one with any resemblance that he could recollect—and he was probably one of the very few people present who saw it—was the Surakhany field of Baku, Russia, first developed about 25 years ago. Here very light white oils were encountered in fine sands at depths down to about 1000 feet. A curious feature of that particular area was the surface issue of gas from time immemorial, and it was a common local occupation of the peasants to burn lime with the issuing natural gas. He might add that the gas often issued from fissures in a superficial limestone bed, but at that time he had, like others, imagined Surakhany to be a "freak" field, and that the gas was probably produced *in situ*. Eventually some of the operators had the courage to drill, when they struck increasing quantities of gas, and at depths of about 700 ft. onwards they struck white oil in quantities up to 10,000 tons a day. Judging by appearances (because at that time they had no means of measuring) the volume of gas must have been in the neighbourhood of 50 to 70 million cub. ft. a day. The gas volume was certainly enormous and uncontrolled, because at that time they were drilling wells of very much larger diameter than to-day, and hermetic casing was not then in use. Finished wells were generally lined with 8-, 10- or 12-in. diameter riveted (stove-pipe) casing. He personally had seen those wells spraying continuously the light oil at a rate of anywhere between five and ten thousand tons a day for months. Subsequently wells carried to 1500 ft. encountered the Baku series, with the ordinary dark oils. It was only then realised that the light oils were simply migratory products from a deeper source. In the Turner Valley the geological conditions were different, and he was inclined to agree with the author's view that oil had migrated from the flanking shales. He was not one of those who subscribed to the theory that oil was formed naturally in the limestones, and he thought one must look to lateral rather than deeper beds for the

origin of the oil. The quality of the Turner Valley oil could be easily accounted for, he thought, by filtration processes. Evidence of migration and filtration was to be found in nearly every field where oils exhibited changed characteristics related to the nature of the strata through which they migrated. He thought Mr. Cunningham Craig was attaching undue importance to the character of oils occasionally struck in the wells in his efforts to trace its origin.

The author had said it was surprising how long the wells held up. It seemed to him that they had little information yet to guide them in estimating the productivity of the fields. In the first place the wells were effectively controlled, whereas in most American fields, until recent years, large gas flows with oil sprays were left open, and no one could ever know the quantity of gas that was then lost. Secondly, there are at present such a few isolated wells which have been yielding at rates of say, 10 to 20 million cub. ft. a day for a few years only. When one was dealing with a limestone structure many miles long, the volumes produced could represent but an infinitesmal percentage of the gas volumes secreted in the rock. He was afraid it would be many years before the real value of the Alberta fields could be assessed; meanwhile, the complex structures, ignorance of source of oil and the high exploitation costs suggests caution in estimates of ultimate profits, notwithstanding the high value of the oil.

Dr. G. M. Lees said the author had raised a number of provocative issues, which called for a certain amount of criticism. He finished his paper by deploring the attitude of this country towards the Canadian oil industry, but he did not state the full case. The great handicap towards the healthy development of Alberta oil had been the periodic epidemic of booms. This had done more than any other single factor to prevent large companies from this side from taking interest in the country. One such boom commenced just before the war. It was for the greater part artificial as it was not based on anything substantial. The only wells at that time were producing on a small scale from the Cretaceous sands in the Turner Valley, and as a production from a lower limestone was totally unsuspected, there was no reason whatever to anticipate that this valley would ever be a big field. It should have been the action of geologists of repute at that time rather to use a moderating influence than to stimulate the orgy of speculation which occurred. Prices went very high, property was taken up wholesale all over the country regardless of location, of structure, and of geological conditions; and the natural thing happened—the market fell flat, and a great number of poor, misguided people

lost their money. Now a second boom was taking place. It was based upon something considerably more substantial in that Turner Valley had proved to be a valuable field ; but geologically speaking it was a freak ; the high pressure gas in a limestone of that nature was something quite unusual among the oilfields of the world. It was not a simple structure ; it was situated in an intensely faulted zone, and the limestone was chopped by reverse faults. It was probably not the only such field throughout the Foothill zone, but under such conditions the proportion of oilfields to structures otherwise apparently favourable would be very small ; one should rather emphasise the speculative nature of drilling in the foothills than strike an optimistic note and single out one or two structures on very insufficient evidence, and say they were likely to be more favourable than others.

The number of companies operating in Alberta at present was enormous. Just before coming to the meeting he had taken a book called the Canadian Oil Book for 1929, with the intention of counting the number of companies operating in Alberta. He had counted up to 100 in the first three letters of the alphabet, and to have completed the book he would probably have still been counting. Many of these companies were badly advised, they had small capital and most of them were entirely dependant on one or two wells ; but they were all optimistic. Many of their geological reports were ludicrous. While he was in Canada two years previously, he had been told of one case where a report by a quack geologist gave as his reasons for supposing that a certain locality had good prospects because "it was underlain by marine rocks containing seagoing animals, such as fossils and larger amphibians."

Another adverse point was that with such a large number of companies no hope of really efficient production could be expected from the fields. With a number of small holdings on a limestone structure, limestone structures having usually very ready communication from one end to the other, the field would be very rapidly exhausted if the wells were allowed to produce freely. There was no knowledge regarding the possible length of life of the Turner Valley field ; nothing was known about edge water, but sooner or later the rash production by small operators, if uncontrolled, might ruin the field. The same would happen with other new fields unless more efficient methods and more co-operation were adopted. That was all a case in favour of large companies rather than small, and in favour of large areas rather than small, although Mr. Cunningham Craig suggested that large areas should not be taken up.

Regarding various geological points which the author had raised, his views on the vegetable origin of oil were, of course, well known

to members of the Institution, and it was not surprising that he should have searched the evidence in Canada for something to fit his theory. He had found it, and he had made a case which he regarded as complete, but the completeness of his case might not seem to others to be well founded. His study of gravities, he admitted, was based on samples from only one well in the field, and he had not got sufficient knowledge of others. As against the origin of oil in the limestone, he said that in the Rocky Mountains there was no known case of traces of oil in the limestone, but a comparison with the Rocky Mountains was not valid. The Turner Valley field was situated in the foothill zone, and in the folded zone in front of the Rockies, and separated from them by the great marginal thrusts. It was not reasonable to suppose that if the mass of limestone of the Rockies ever had contained oil, even a trace of it would necessarily still be left, when one considered the enormous thrusts and compression and subsequent exposure to which it had been subjected.

He found the author's case for downward migration very difficult to accept. If gas was capable of migrating downward and building up high pressures, why should it not find its way up again? What held it down? What is the nature of the cap rock which allows downward migration for a long period, then reverses its functions and seals off gas pressures of 2,000 lb. to the square inch, and more? In the early days one used to regard a cap rock as necessarily a shale formation, but in the case of the limestone field of Turner Valley, and of many other limestone fields, a well may have to be drilled sometimes 200 or 300 ft., and in the Turner Valley sometimes as much as 800 or 1,000 ft. in the limestone, before striking high pressure gas or oil. In the case of the Turner Valley, the structure is situated in a zone of strong compression. There were well developed reverse faults, and it must be imagined that the whole limestone had been strongly pushed and shattered; yet what held in such high pressure gas right inside the main body of the limestone, separated from the shale by a considerable thickness of other limestones which must also be supposed to have bedding planes, joint planes, and to be somewhat shattered?

The author also stated that Dr. Bosworth did not find a trace of oil throughout the Fort Norman area in the limestone, but in the North-West Territory there were many known cases of apparently indigenous oil in Devonian limestone and shales.

These were really criticisms of the author's view. If the speaker were asked what his own view as to the origin of the Turner Valley gas was, he would say he did not know. If it was derived from the Lower Cretaceous, he would rather regard it as having entered the limestone from the Lower Cretaceous via the reverse faults on the eastward flank. He could not conceive that it could have migrated

normally down through the shales and built up such enormously high pressure underneath. It was quite possible that there were several indigenous horizons. The limestone oil might belong to the Devonian limestone or to some shales associated with it, and the Kootanie and Dakota oil might conceivably be indigenous to their own horizons, and quite separate and distinct. It was for this reason among others that he said the Turner Valley was a freak. The origin of the oil was uncertain. If it had migrated into the limestone via reverse faults, it does not follow that similar conditions would be duplicated elsewhere. He deprecated the picking out at random of two structures and being so optimistic regarding their prospects. Such action can only further stimulate the orgy of speculation which had already exceeded justifiable limits. Geologists would be doing a much better service to Canada and would make it more possible for companies from this country to operate, if they were to strike a more moderate tone, and to emphasise the difficulties, and the speculative nature of all the Foothill structures. He hoped, just as much as the author, that some more good fields would be found, but with such complicated conditions their location will be a matter of great difficulty.

Colonel W. G. MacKendrick, D.S.O., said that he had gone over the Alberta oilfields with such wisdom as had been given to a road builder, to see what an ordinary man could see. The last speaker had said that the Turner Valley field was a freak. Anything that put out oil at the rate at which the Turner Valley field was putting it out to-day was, in his opinion, far from being a freak, but Canada's largest oil concern owns 85 per cent. of this freak oil field in Turner Valley. They had deprecated it for ten years as a gas field only, but they thought well enough of it to buy it. From Turner Valley running down south, and he was not an oil man nor a geologist, he had seen the oil seeping out, not on one occasion but on dozens. From what he had seen, he believed that Canada had one of the largest undeveloped oilfields in the British Empire. Canada was developing it at a time when it was going to be needed. There would be some failures of course, because when there were many companies going in with few acres in untested territory they were bound to go wrong at times. The last speaker had referred to Mr. Craig's idea of small holdings. He had gathered that it was an entirely different view that Mr. Craig held, that it was Mr. Craig's view that it was well selected holdings, distributed over the country, which would in the end yield the best returns. He thought Alberta had a real undeveloped oilfield and, he was certain from the wells that had been drilled, and the testings made, which showed it from the Montana border right up into the Arctic Circle, it would be found

that whenever there were oil domes there would be good oil. A friend of his had told him that up in the Peace River district they had the best lubricating oil in the world. The trouble now was to get it out. Those things, in time, would be developed so that they could be worked even in the cold weather. Canada in a few years would produce all the oil required in that section of our Empire and cheap oil would build up industry in Western Canada.

Mr. E. H. Cunningham Craig (in reply) said that Dr. Lees had said a good deal about the booms in Calgary. He (the speaker) had been through the first two booms in Calgary, and had told people publicly that 75 per cent. of the wells being drilled had no chance of striking oil ever; but nothing could stop the booms then. The failures were chiefly due to lack of money, and to locating wells absolutely off any kind of structure at all. Geologists were scarce in those days; at least, those that could really call themselves geologists. And in some cases the failure was due to not getting deep enough. But the curious point was that many big companies had sent geologists there, they had spent a month or two there, perhaps, they had seen a lot of country, and had come away, and somehow or other they seemed to have missed the main points that were there. Perhaps they did not stay long enough.

He had not given anything like all the details he could give about the filtration of oils, and the different oils. There was a great deal more that could be put in, but the gradation, the gradual change in the oil away from the parent source, was the point he wished to make, and that, he thought, was pretty well proved, not only in one well but in several.

Dr. Lees had said something about isolated wells. He had shown only a few wells on the map, but the wells were not isolated. Wherever there was a good well there were nearly always three or four more drilled close round it, and they were yielding gas at a good rate. No one knew how long the wells would last, but it was definitely known that there were thousands of feet of limestone below. All the limestone contained some gas, but it was only from those dolomitised bands that it was delivered in anything like reasonable quantity.

As for the water, they had not found any water yet in the Turner Valley. Water might be found some day. No doubt it would. As for optimism, if Dr. Lees would spend a year or two going over that country, studying it carefully, working out the structures and the stratigraphy, he thought he would be enthused with a considerable amount of optimism also. Brief visits and casual examinations could only result in erroneous opinions being formed.

The reason he had said he was not in favour of large areas was simply that taking up a huge area, with perhaps one little structure in it in one corner, he did not consider to be good business. It was better to take up that one little structure, and take it up completely, than to take twenty square miles all round about it where there was no structure at all. It was for that reason that he did not believe in taking up a huge area of ground, but rather believed in picking the localities carefully ; and if that had been done in the past there would have been fewer failures. It was going to be done in future, because the geological work over there was being much more carefully attended to ; there had been many good geologists over there, and they were selecting their areas carefully, sometimes on one theory, sometimes on another ; but at any rate, the ground for exploitation was being selected carefully.

As for indigenous oil in the limestone anywhere, he would be very glad if Dr. Lees would show him any in that country, for all the oils he had ever known of from the limestone, either from the Athabasca in the north or in any locality right down to Montana, were obviously filtered.

He thanked the meeting very much for the way it had received his paper.

On the motion of the **President**, a hearty vote of thanks was accorded to the author.

The following contributions to the discussion were received subsequent to the meeting :—

Mr. T. G. Madgwick wrote :—

Mr. Craig's paper is to be welcomed as a valuable contribution on account of the publicity it gives, not only to the oil and gas fields of Alberta, but to the strange indifference to their still largely undeveloped possibilities on the part of British capitalists. That such excellent results as have already been obtained with the aid of a moderate amount of drilling, spread over the great area of the vast potential oil and gas area of Alberta is indeed a matter that should have attracted greater attention and the failure to do so is attributable probably to the prevailing overproduction in other parts of the world rather than to any lack of appreciation of the prospects of Western Canada. Whether it would be as difficult now for a British company or any other new interest to share as satisfactorily in the results, which are to be looked for in the near future as Mr. Craig would appear to suggest towards the close of his paper, is a matter that depends on how far the present development has tested the potentialities of the whole. This in turn raises the question of whether the development has yet afforded the key to

the tectonics of the Foothills and thus can guide us to a rational prospecting of the many areas that yet call for testing.

It is generally felt that the more intensive drilling programme of the past few years in Turner Valley and adjacent areas is affording us the basis for what can be regarded as a typical structure, but it is still premature to advance outwards except with caution, especially bearing in mind the hazard of great drilling depths that await the unwary locator in the Foothills. For this reason the present writer hesitates in assuming that the plums have all been picked from the areas that will eventually become oilfields.

As an illustration of the difficulty in interpreting structures we have Mr. Cunningham Craig's statement in regard to Turner Valley, that "from east to west the productive area is already well defined, varying between one and one and a half miles." The eastern margin is already very well defined in parts but the western still awaits delimitation. For this reason, even in the best drilled area, contrary to Mr. Cunningham Craig's opinion, it is advisable for companies to hold large acreage under lease pending a solution of the structure. Exactly what this may some day be proven to be is a question which few would care to answer at the present time. That overthrusting plays a much greater role in the tectonics of the Foothills than was formerly credited would now be generally accepted. That the structure of the complex area of Cretaceous rocks to the west of Turner Valley affords any immediate guidance to that of the underlying Palaeozoics is again open to discussion. It might yet be proven that the limestone in Turner Valley itself is not autochthonous, in fact the writer has long been prepared to find this the case.

Two factors that will have to be taken into any consideration of the Foothills structure might here be pointed out. The first is the fact that in the Moose Mountain on Canyon Creek the Fernie Shales lie directly upon Palaeozoic limestones from which the Triassic rocks and possibly the Rocky Mountain Quartzite[1] have been eroded, both however being found in the "nappe" towards the west, and the other is the absence of the Upper Cretaceous between this same "nappe" and the one next above it, which can easily be seen at places like Canmore. Here we have evidence first of all of the big easterly movement of the "nappes" to the west relative to the limestone in Moose Mountain, the difference in amount of pre-Fernie erosion of the two sections being some measure of their original distance apart, and secondly it is obvious that the whole Upper Cretaceous (and Blairmore) has in places been ploughed forwards in front of the advancing "nappe" and may be represented

[1] Hume, Summary Report, 1927, Part B, Geological Survey, Dept. of Mines.

now perhaps in part, in the contorted Cretaceous rocks above referred to lying west of Turner Valley. Whether this extra load has prevented the emergence of still another "nappe" further east with the result that this has simply pushed its way into the autochthon of the Alberta syncline, the overlying sediments now forming the Turner Valley "anticline," or whether the limestone so buried has broken up and itself lies in a series of fault blocks beneath the Cretaceous of the Foothills is a matter that will require many more feet of drilling to determine, unless some of our geophysical friends can come to our aid in its determination.

Bearing this in mind some caution would appear to be in place in any speculations as to the ultimate source of the oil and gas met with in Turner Valley. On the Prairies, remote from the complexity of the Foothills, although not always entirely free from faulting, oil and gas are found in various horizons of the Mesozoic strata and would appear to be near their source stratigraphically. Thus we have the important Medicine Hat gas sand in the Milk River Sandstone of Montana age, the Bow Island and Foremost gas sand in the lower part of the Colorado, which in turn may be represented at Wainwright, Viking, Ribstone by gas and oil horizons near the base of the Colorado (Viking gas sand, Wainwell oil and gas sand). Then at Wainwright and elsewhere in Central Alberta occurs the "B.P.3" oil sand in the Lower Cretaceous. In Southern Alberta we find the "Sunburst" oil sand (at the top of the Jurassic) named after the productive horizon in Montana and finally the "Ellis" of Jurassic age.

The fact that most of these may be said to have a counterpart in Turner Valley, where even the basal bed of the Colorado affords at times small quantities of heavy oil (35°–43°Be) would militate against too facile acceptance of the oil in these horizons having all originated in the Kootanie. The most definite evidence of possible oil *in situ* so far published is that of the bituminous character of the uppermost layers of the pre-Fernie limestone and dolomite in Canyon Creek in the Moose Mountain area, some 20–25 miles west of Turner Valley. Here Dr. G. S. Hume[2] describes the limitation of the bituminous impregnation to the top 325 ft. of the limestone, the marked occurrence being in certain porous and cavernous layers separated by compact rock. This would appear to correspond so closely to what has been observed in cores in Turner Valley as to suggest something more than a mere coincidence. That on occasion the productive capacity of a certain volume of limestone penetrated by the drill may be enormously enhanced by fissuring, shearing, etc., may easily be seen, when the complex structure of Turner Valley is remembered.

[2] Loc. cit.

Mr. Cunningham Craig comments on the fact that no absorption plant is in use in Turner Valley. There is a plant but it is no longer in use. From results obtained on some wells it would appear that practically all the wild fractions can be taken out of the gas by keeping sufficient pressure on the separator. The problem, which is receiving consideration, is to find a market for these valuable products.

It would seem that Mr. Cunningham Craig is rather lukewarm as to the prospects of oil under the Prairies. Thus, under the heading " Proved Fields and Unproved Structures," he refers to the proving of the Wainwright field as a producer of heavy oil in small quantity, whilst his remarks re the Skiff area would scarcely do justice to the interesting development in that locality, where all the wells have not been abandoned and it is hoped a useful field will result. Then again it is too early to refer to the international structure which has been recently proved by the Vanalta Well as a " small " dome. Apart from this, very encouraging results were obtained during the past year at Ribstone (near the Saskatchewan border, east of Wainwright) and at Oyen (also in the eastern part of the Province), and in all these areas the oil is far from being of the nature of " inspissated residuals " that the Wainwright crude is described as. The typical Prairie type of oil runs from 18°–21° A.P.I, whilst the higher gravity of the Vanalta oil (31°) would seem to favour a rise in grade as one approaches the mountains.

The Wainwright field, which is not situated on any gentle anticlinal rise, as was formerly supposed, but on local structures on the general rise east of the Alberta Syncline, is in reality a very promising field, where drilling costs are low, depths moderate and being situated right on the C.N.R. main line is exceptionally well located for development. The only need is a systematic core drilling programme to work out the structure over a wide area, the general covering of glacial drift making this otherwise difficult to determine.

Dr. G. S. Hume wrote :—

The outline of the stratigraphy and oil prospects of Alberta, given by Mr. Craig, contains a number of statements which do not agree with the opinions generally held by Canadian geologists. Since Mr. Craig states that " a brief review of the geological conditions is necessary in order that the problems to be solved may be clearly understood " it seems desirable to call attention to a stricter definition of stratigraphic terms as used by the Geological Survey of Canada than has been used by Mr. Craig.

In the Kevin-Sunburst oil field of Montana the Madison limestone of Mississippian age underlies Ellis shales of Jurassic age. In the Turner Valley area limestones that may be Mississippian underlie

the so-called Fernie shales of Jurassic age. It is by no means certain, however, that these limestones are Madison and since the use of this name in Turner Valley implies a correlation which has not been established, its use should be avoided, although undoubtedly in parts of Southern Alberta, 150 miles to the south-east the limestone underlying the Ellis formation is the same age as the Madison of Montana.

The Dakota formation was described in the United States and is Upper Cretaceous in age. Geological studies have shown that at the present time no typical Dakota rocks are known in Canada and although the name "Dakota" was formerly used in Canada for the series of strata overlying the Kootanie and underlying the so-called Benton, later studies have shown that these strata are mostly if not entirely of Lower Cretaceous age and hence since the name Dakota, which represents strata of Upper Cretaceous age, was no longer tenable, the name Blairmore was introduced. Underlying the Blairmore in the Foothills of Southern Alberta is the Kootanie in which, as Mr. Craig states, workable seams of coal occur. The coal is, however, bituminous and not anthracitic.

Above the Blairmore strata are the Benton shales. These are mainly Colorado in age although the uppermost part carries marine Montana fossils. It was this upper part that Cairnes[3], in the Moose Mountain report, correlated with the Clagett which is Montana in age. It is now known, however, that the Montana fossils are confined to a few hundred feet of strata at the top of the marine shale group and that below them and above the Cardium are over 1,500 ft. of Colorado shales. The use of the name Clagett by Cairnes was unfortunate, and descriptions of the stratigraphy in the Moose Mountain area have been given in recent reports by the Geological Survey. Mr. Craig in his geological table places the Benton in the Lower Cretaceous. It is as far as known entirely Upper Cretaceous.

In the Foothills and Western Plains in many places it is very difficult to separate the Edmonton from the overlying Paskapoo formation although in other places an erosional interval between the two formations is clearly indicated. The Edmonton formation has always been considered by the Geological Survey of Canada as Cretaceous in age whereas the overlying Paskapoo is Tertiary.

In regard to the Mackenzie river oil discoveries, Mr. Craig states that "the oil was only found on the flank of an anticline where Cretaceous strata are piled upon it. It was in the Cretaceous strata that the oil was struck." Oil was found in two wells on the east side of the Mackenzie river north of Fort Norman. Both of these wells commenced drilling in the Bosworth formation which carries the

[3] Cairnes, D. D., Moose Mountain District, Southern Alberta; Geol. Surv., Canada, Memoir 61, 1914.

Spirifer disjunctus fauna of upper Devonian age. The oil was struck in both wells in the Fort Creek formation also of upper Devonian age and underlying the Bosworth formation. The seepages of oil that occur in many places in the Mackenzie area are as far as known confined to Devonian strata and the only well that penetrated a small thickness of Cretaceous above the Devonian on the west side of the Mackenzie river obtained no oil.

Under the heading "Source of the Oil" Mr. Craig states that the "famous Lineham well" was drilled in an area where seepages of oil occur in the Kootanie and Dakota beds. The writer has no first-hand knowledge of this area but as early as 1891 Dr. A. R. C. Selwyn of the Geological Survey pointed out that these seepages were so remarkable in that they occurred in Lower Cambrian strata, and Dr. G. M. Dawson later suggested that the oil may have been derived from Cretaceous strata below an overthrust. The complications of structure within the area are so apparent from a study of Dr. D. B. Dowling's cross-sections published by the Geological Survey that the choice of this area as illustrating the stratigraphic horizon from which the oil originated would not seem to be very apt. It should be mentioned, however, that in other parts of the Foothills seepages of oil do occur in Lower Cretaceous rocks but all seepages are not confined to rocks of this age.

Mr. Craig cites the Mackenzie area as an illustration of oil in the Cretaceous. It has already been pointed out that the oil is in the Devonian in the Mackenzie area.

Mr. Craig also states that the gas sands at Bow Island, Viking and Wainwright, are in Lower Cretaceous strata. In these areas it is very difficult accurately to draw the dividing line between upper and Lower Cretaceous, especially from well samples. The gas sands at Bow Island and Viking have been considered to belong to the Benton (Upper Cretaceous) rather than to the Lower Cretaceous, but as oil accompanied by gas occurs in sands in the Lower Cretaceous at Wainwright, there is a possibility that the gas sands at Viking and Bow Island may be Lower Cretaceous. It would not be agreed, however, as Mr. Craig states at this point in his discussion that "so far the case is perfectly simple," although it is quite true that "the great outcrop of the Athabasca Tar Sands is an excellent testimony of the petroliferous nature of the Lower Cretaceous horizons."

Mr. Craig has done a service in drawing attention to the oil fields of Western Canada. The Foothills of Alberta offer an opportunity for the study of many interesting problems in connection with the origin and concentration of petroleum and it seems highly probable with the active drilling program now being carried on, new and important oil fields are likely to be discovered in the next few years.

Mr. E. H. Cunningham Craig wrote, in reply :—

He wished to thank Mr. T. G. Madgwick and Dr. G. S. Hume for taking the trouble to send such interesting and important contributions to the discussion ; their knowledge of the geology of Alberta gives great weight to any opinions they are good enough to set before the Institution.

In answer to Mr. T. G. Madgwick, he had not had access to a sufficient number of well-logs to give a detailed account of structure in the Turner Valley, but the presence of reversed faults of large hade has been proved. He hesitated to give them the title of thrusts, because it would deprecate the frequent use of the word thrust by so many geologists who have never mapped an area where real thrust planes are the dominant feature.

As to the hade of the reversed faults, he found it difficult to obtain sufficiently definite evidence : hades of 40 and 50 degrees have been proved, but it is probable that the major reversed faults may have much greater hades in some localities, and that the minor faults are merely riders to these more powerful dislocations.

Whether the limestone is affected by these reversed faults or not, has been, and is, an interesting but difficult problem ; the latest evidence to hand suggests that the limestone is not immune from these fractures.

The oil-bearing horizons correlate fairly easily in all localities that he had studied : where oil occurs in the limestones it is confined to bands rendered porous by dolomitisation or some other cause, and is always to a greater or less extent filtered.

He did not wish to belittle the results obtained by drilling in the prairie structures, but must point out that for quality of oil and thickness of oil sands the best results are to be looked for nearer to the Foothills.

In answer to Dr. G. S. Hume, he pleaded guilty to using nomenclature for the various groups of strata that may be quite out of date, but considered these matters of more academic than practical importance, and used terms in general use in the oilfields.

At the same time he was inclined to draw the line between Upper and Lower Cretaceous somewhere in the Benton Group, and to hold that the Edmonton Group extends upwards into the Eocene.

The Kootanie coals vary, according to their environment and history, from bituminous to anthracite.

He was unaware that the Fort Norman oil had been proved to have been struck in Devonian strata, but in any case my statement holds good that all oils struck in the Devonian occur where the Cretaceous overlies that formation, or has only recently been removed by denudation.

There is no doubt whatever about the seepages from the Kootanie in the neighbourhood of the Lineham well; both thrusting and recumbent folding bring older formations above the Lower Cretaceous beds in that locality. This is obvious to anyone who has visited the ground.

With all deference to Dr. Hume's wide knowledge of the ground, he still considered the problem of the source of the oil as comparatively simple.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND TWENTY-SIXTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the House of the Royal Society of Arts, John Street, Adelphi, London, W.C. 2, on Tuesday, March 11th, 1930, Dr. A. E. Dunstan, President, in the Chair.

The President, after announcing that the Annual General Meeting of the Institution would be held on Thursday, 20th instant, at the Royal Society of Arts, at 5.30 p.m., said it was a great pleasure to him to introduce to the meeting a member of the Institution of long standing, an eminent specialist in his own particular line, who was about to read a paper on an exceedingly important subject; indeed, it was one of the most important papers of the year, and one in which much interest had been evoked as was shown by the very excellent attendance.

The following paper was then read :—

The Diesel Engine as Applied to Road Transport.*

By MAJOR W. H. GODDARD, A.M.I.Mech.E. (Member).

To those who follow industrial and commercial progress in general it has been evident for some little time past that the Diesel Engine will in the near future probably occupy an important place in road transport in this country. The reasons will be dealt with fully in this paper. As a matter of actual history it is now some 20 months since the first actual production vehicles driven by Diesel engines arrived in this country from the Continent, and created a considerable amount of interest in transport circles. From that date (April 1928) until quite recently no great progress in actual Diesel transport was made, and indeed even to-day there are probably not more than 25 vehicles of this type running on our roads, but as a result of a great deal of spade work and demonstration tests during this period, both here and on the Continent, a considerable increase should be apparent in the very near future. It has in fact been a period of study and observation. As a Nation we are conservative and slow to take up anything new and progressive, and this, combined with the heavy import duty on foreign motors undoubtedly contributed to the slow coming of the Diesel. For the moment the duty still

* A precis of this paper will be found in Abstract No. 545.

exists, and therefore unless our manufacturers wake up and produce a really good Diesel that will compare favourably with those now being produced by our Continental competitors, progress will still be slow. It is known that several manufacturers are now busy experimenting, but actual production has not yet been attained. It has been suggested that the Continental firms have a monopoly of the patent designs giving the best results, and this is probably true to a certain extent, more particularly when it comes to the fine art of producing a really silent engine (as compared with a petrol engine) with sweet exhaust, without any curtailment of power or acceleration. Small Diesels of the stationary type, although heavy and running at comparatively low speeds, can be and in fact have been put into lorries in this country, but this type is quite unsuitable for passenger vehicles and even for lorries is not a proper transport job, and not to be compared to the Continental machines. As, therefore, we have not yet in this country produced a really satisfactory Diesel or heavy oil engine for road transport use, this paper is naturally confined to Continental engines, of which there are a considerable number, probably over a dozen, all of which are interesting and some even fascinating.

A study of the different ideas and designs of these engines is not only interesting but will enable us to more quickly form an opinion and perhaps be able to criticise, when the time comes for this country to produce Diesels for transport use.

Before describing these engines it is perhaps advisable just to go into the fundamental points of difference between the carburetter or petrol engine, and the heavy oil compression ignition engine. Briefly, then, a petrol engine consumes all the oxygen in the air contained in the working charge or mixture, but not all the fuel, a good part of which is wasted and finds its way to the sump. The Diesel engine consumes all the fuel in the working charge or mixture but requires at least 100 per cent. excess air for smokeless combustion, a great part of which is expelled in the exhaust.

Air is cheap. Petrol is not. Hence one item in the economy. There is evidently an ideal to be attained which lies somewhere between these two systems, and this ideal will probably result in the production of an engine with a greater thermal efficiency than has ever before been possible. It does not appear to be impossible and may come even sooner than is generally expected. But, as we have at this moment, thanks to Continental engineers, an engine fully tried out, and proved over sufficient time to enable a sound opinion to be formed, which will actually do the same work as a petrol engine at roughly one sixth of the fuel cost (at present prices), we must be contented and well satisfied.

The following is a tabulated list of the points of comparison between the petrol and the Diesel engine:

Diesel Engine.	Petrol Engine.
Thermal efficiency, 35–36 per cent.	Thermal efficiency, 22—23 per cent.
Will run satisfactorily on a very wide range of heavy and residual oils. Diesel, fuel, gas oil, tar oils, etc., all of high flash-point and to-day at about one-third cost of petrol.	Will only run on petrol, and the quality of this must not vary greatly. Petrol is of low flash-point and highly dangerous to store and handle.
Fuel supplied to engine by positively driven mechanical pump at exact moment of maximum compression and charge is ignited by heat of compression. No fuel can be wasted. Great efficiency at fractional loads.	Mixture of air and petrol gas drawn in through carburettor in unsatisfactory manner. Fuel wasted, especially at fractional loads.
Compression ratio can safely be taken to 16—1 or even higher. Only limited by heat and stresses. Thermal efficiency depends directly on heat of compression.	Compression strictly limited to max. of 8—1. This in special cases. Usual limit 6—1, owing to self-ignition of mixture.
In multi-cylinder engines exact and equal distribution of fuel charge.	Unequal distribution of mixture is unavoidable.
Period of burning and expansion produces power stroke of considerable duration resulting in high average torque at all speeds.	Average torque effort poor owing to violent explosive nature of charge.
Starting, even in coldest weather, can be effected in one minute or less. No delay waiting for engine to warm up. Load can be pulled as soon as started.	Difficulty in starting in cold weather. Time needed for warming up before load can be taken.
Entire freedom from danger of fire both on vehicle and in storage, and in haulage of bulk fuel.	Great danger of fire at all times both on vehicle and in storage, also in haulage of fuel.
Elimination of delays due to mechanical defects in auxiliary apparatus.	Magneto, carburettor and plugs frequent cause of delays.
Very perfect combustion resulting in high thermal efficiency, and entire freedom from sump dilution and also no interference with cylinder lubrication.	Imperfect combustion. Always a surplus of fuel resulting in sump dilution, poor cylinder lubrication, formation of hard carbon, and poor thermal efficiency.
Reduction to practically nil of carbon monoxide gas in exhaust gases.	Dangerous amount of carbon monoxide in exhaust gases.
10—15 per cent. more miles per gallon of fuel owing to heavy nature of the fuels used. Sp. gr. approx. 0·870/0·880.	Sp. gr. of petrol approx. 0·730, *i.e.*, 1½ lb. less per gallon.
Heat lost in radiating water, 37 per cent.	Heat lost in radiating water, 50 per cent.
Air drawn in to cylinder enters freely from the open. Is not required to perform the function of fuel atomiser.	Air required has to be drawn in through restricted choke to produce required fuel atomisation.
High average torque results in better top gear performance, and therefore higher average speed.	Low average torque results in more gear changing than is required with the Diesel.
Prolonged and steady expansion stroke reduces wear on tyres.	Violent explosion of cha ge tends to short life of tyres.

With regard to fuel economy and price of fuel, it should be borne in mind that quite apart from price of fuel, this engine will do approximately twice the miles per gallon, so that even if the price of fuel was equal to that of petrol we still have a very substantial margin of benefit.

Perhaps the greatest benefit of all is the fact that there is complete freedom from danger of fire, both on the vehicle itself, and also in storage and in bulk haulage of fuel. One of our most important transport chiefs mentioned to the author that to his mind this was far above the importance of the economy, although this was also important. Undoubtedly for passenger transport it is a very great point.

The different categories into which we can classify these engines are roughly as follows:—

Four-stroke engines.
Two-stroke engines.
Direct injection engines. (Including opposed piston type.)
Pre-combustion chamber engines.
Those with and without air compressors.

From a well-known German Technical journal a list (Table I) has been taken of the more prominent makes with their principal data, and will be found quite interesting, as it gives a good idea of the points which Continental makers have incorporated in their machines. There are nine on the list and they are all German. This is to be expected as Dr. Diesel himself was German and the engineers of that country have been the pioneers in this progressive work, and we must give them full credit for all the hard and difficult research and experimental work which they have carried out in order to bring this machine to such a very satisfactory state of perfection.

It should be noted that 8 out of the 9 makers favour the 4-stroke principle. This is a significant point and may be of considerable importance as time goes on and these engines come more into general use.

Four makers favour the direct injection system of fuel and three favour the pre-combustion design. This will be another basis for controversy at a later stage.

Of the remaining two, one reverts to the original system of Dr. Diesel, *i.e.*, the use of air blast injection, and the other one uses a design of chamber which is somewhere between the p.c. chamber and direct injection, a sort of inverted air pocket in the piston with a venturi opening.

Injection pressures vary enormously, from 950 lbs. to over 10,000 lbs. per sq. in. The 6-cylinder design appears rather more popular than the 4. Weight per H.P. varies from 7 to 12 kilogrammes per B.H.P. Speeds vary from 1,000 to 1,400 r.p.m.

TABLE I.

Engine.	Working Principle.	No. of Cyls. Bore and Stroke (m.m.).	Capacity in Litres.	Normal.			Pressure of Compression (Atmos.).	Max. Pressure at Firing (Atmos.).	Pressure of Injection (Atmos.).	Weight per H.P Kilogs.	Method of Starting.
				Speed.	H.P.	H.P. per Litre.					
Maybach.. ..	4-Stroke air injection	6×140×180	16·6	1300	130	7·9	—	—	—	8	—
Mercedes Benz.	4-Stroke precomb. ch.	6×105×165	8·55	1300	70	8·2	35	40	60	9	Glow plug
Deutz	,, ,,	4×115×190	7·95	1000	40	5·0	35	45	80	10–12	,, ,,
,, ...	,, ,,	6×115×190	11·90	1000	60	5·1					,, ,,
Körting	,, ,,	6×130×180	14·40	1200	90	6·2	40	42	60	,,	,, ,,
Bosch-Aero ..	4-Stroke air-pocket	2×110×170	3·25	1200	20	6·2	32	45	80	5	—
M.A.N.	4-Stroke direct jet	6×120×180	12·3	1000	70	8·7	25	45	300	9	Warming in advance.
Linke-Hofmann	,, ,,	4×115×165	6·90	1200	50	7·2	30	42	300	10	—
,, ,,	,, ,,	6×115×165	10·40	1300	90	8·6			300	10	—
Krupp	,, ,,	4×135×200	11·50	1000	65	5·6	33	42	350	8	—
,, ...	,, ,,	6×135×200	17·20	1000	100	5·8			350	8	—
Junkers	2-Stroke direct jet	2× 80×300	3·0	1200	45	15·0	40	55	700	7–8	—
,, ...		3× 80×250	3·8	1400	70	18·5			700	7–8	—

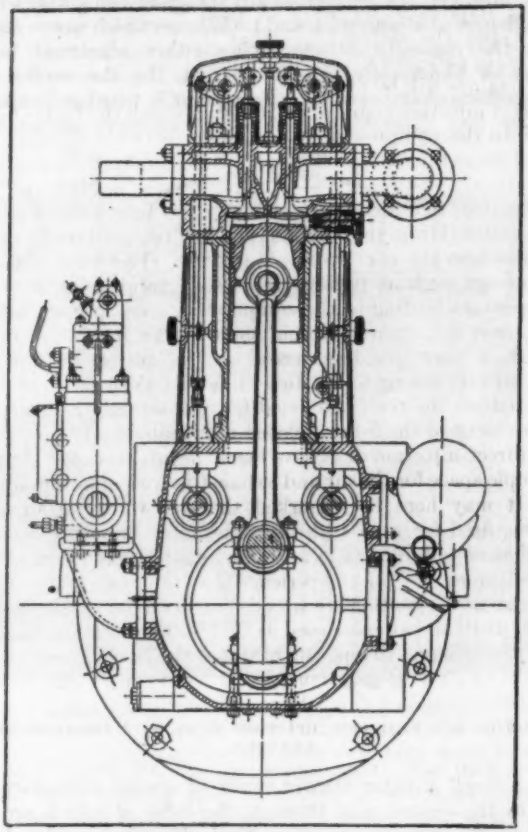
B.H.P. per litre capacity in the 4-stroke engines ranges from 5 to 8·6, and in the 2-stroke opposed piston engine from 15 to 18·5. Comparing the two main types, *i.e.*, direct injection and the pre-combustion chamber design, the following notes may be of interest:

It being impossible for want of time to go fully into all the different types, the author hopes that the following description of the two main categories, *i.e.*, direct injection and pre-combustion chamber engines will be of interest.

(1) Direct injection engines, *i.e.*, those in which the fuel is injected directly into the compression space proper between the top of the piston and the cylinder head, such as M.A.N., Linke-Hofman, Krupp. (2) The pre-combustion chamber design, such as Mercedes Benz, Deutz, Körting, in which the fuel is sprayed into a small enclosed chamber, isolated from the cylinder, and incorporated in the cylinder head, and where the combustion is started. There are also variations in design such as partially enclosed chambers with venturi-shaped openings leading to the compression space proper, also partially recessed but open spaces in the cylinder head, and in some cases with a corresponding recess in the piston head. These, however, strictly belong to the direct injection type, as these designs cannot produce the results claimed for and actually resulting from the employment of the fully enclosed pre-combustion chamber.

In the direct injection design we have the advantage of simplicity and of ample space for the air and exhaust valves, undoubtedly good points. It may here be remarked that as we are dealing with engines required for road transport, the most important consideration is that of obtaining a clear and comparatively sweet exhaust. It has been found by long experience that to obtain complete combustion, the first essential towards a clear exhaust, with the heavy type of oil distillate which is used as fuel in these engines, the atomisation of the fuel and the mixing of this with the charge of hot compressed air, *i.e.*, turbulence, must be of a very high order. In the original Diesel engines this object was attained more easily by reason of the fact that the fuel was blown in by compressed air blast, but in these compressorless engines the conditions are vastly different and the turbulence and atomisation must be carried out in the engine itself. It is difficult for those who have not had experience with these engines to realise the difficulty of obtaining sufficiently complete atomisation and violent turbulence to attain the desired combustion and exhaust conditions. It is, perhaps, the most important point in the design. With the direct injection design, both atomisation and turbulence are mostly dependent on the pressure of injection of the fuel, and these engines are, therefore, somewhat limited in this direction. In one well-known design the pressure of injection is 700 atmospheres, or well over 10,000 lbs.

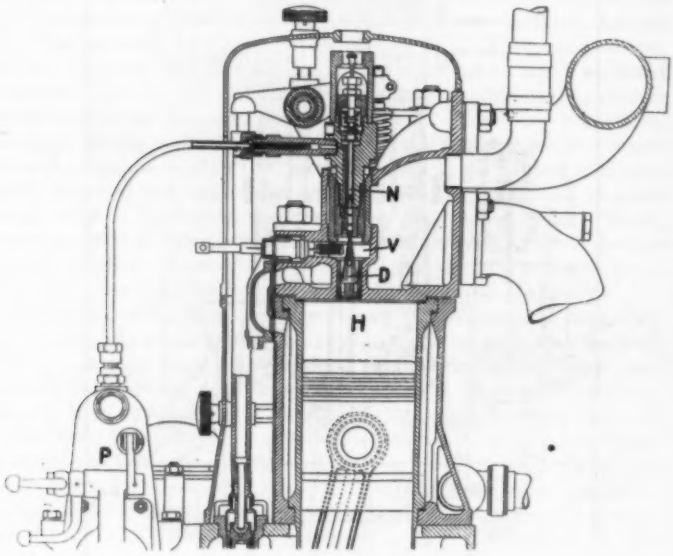
per sq. in. It is logical to assume that for vehicles on the road, subject to continual vibration, it is not desirable to carry such extreme pressures on any part of the engine.



THE 6-CYLINDER 4-STROKE "DIRECT INJECTION" M.A.N. ENGINE.
70 B.H.P. AT 1000 R.P.M.

In the pre-combustion chamber design, space has to be found in the cylinder head for this chamber, and this naturally entails a slightly more complicated casting and a somewhat taller engine. In practice, however, no difficulty has been found in fitting in this

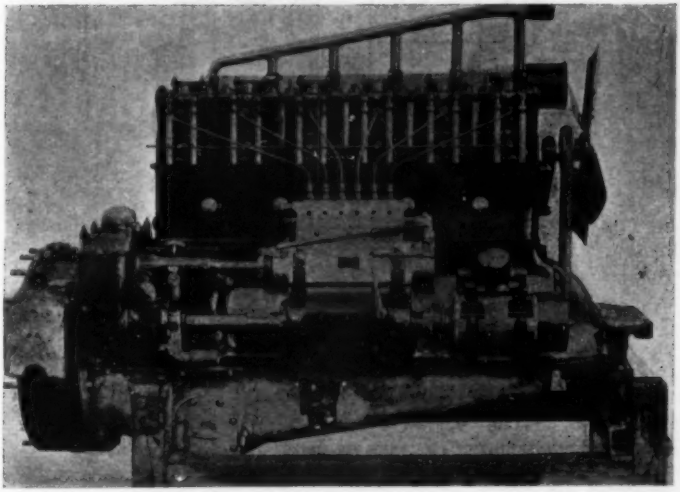
chamber while at the same time leaving ample space for the air and exhaust valves, and, with an overhead valve engine, the extra height is of no importance. Against these slight disadvantages we have, however, the very great advantage of being able to secure the high degree of atomisation and turbulence which are so essential, without the necessity of employing either abnormal injection pressures or abnormally shaped pistons. In the centre of the pre-combustion chamber at its lowest point is fitted a "vaporiser."



SECTION OF MERCEDES-BENZ CYLINDER HEAD WITH PRE-COMBUSTION CHAMBER.

This is a small circular fitment made of special refractory metal, hollow in the centre, and through the sides of which are cut or drilled small passages in a vertical direction, and which all converge at the bottom into one "flat cone" shaped orifice. This latter is the only connection between the pre-combustion chamber and the compression space proper of the engine. The action of this chamber is as follows. The engine cylinder having drawn in a full charge of pure air on its suction stroke, the piston on rising on the compression stroke compresses the air to about 500/550 lbs. per square inch, the temperature rising accordingly. The fuel

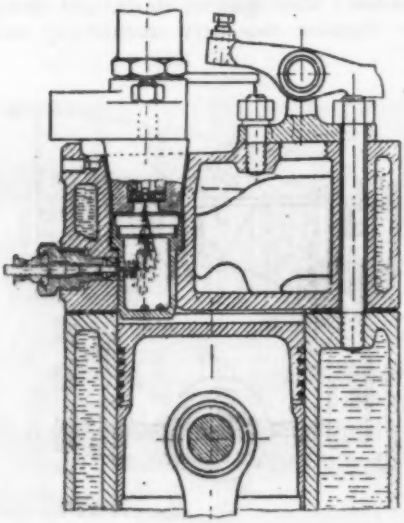
pump is timed to inject its charge of fuel into the pre-combustion chamber at about 10 degrees before top dead centre. At this moment the chamber is full of highly compressed and heated air, the temperature attained being sufficient to ignite the charge of mixed oil spray and air. The injector nozzle is situated in the centre of the chamber at its uppermost point, and the shape of the spray is so arranged that the oil mist is spread all through the air in the chamber. Thus ignition starts, and immediately the pressure in the chamber rises very considerably and reaches a



MERCEDES-BENZ 8½-LITRE, 6-CYLINDER ENGINE.

maximum of about 600 lbs. per square inch. The only means of escape for these burning gases is by way of the small passages in the vaporiser, and finally through the one and only single passage into the cylinder. The high pressure attained then forces all this charge into the cylinder, where it meets the remainder of the heated air charge. The capacity of the pre-combustion chamber is one-fourth of the total compression space of the cylinder, so that when the primary ignition occurs we have all the oil fuel charge mixed with one-fourth of the hot air charge, *i.e.*, a rich gas. On being ejected into the main compression space it mixes with the remaining three-quarters of the air charge, forming the proper

mixture. On passing through the vaporiser, extraordinary atomisation and turbulence are obtained, the whole charge then burning and finally expanding to produce the working pressure of the engine. The injection period is from 10 degrees before to 25 degrees after top dead centre, or about one-tenth of the crank circle. This results in a period of "constant pressure," a very

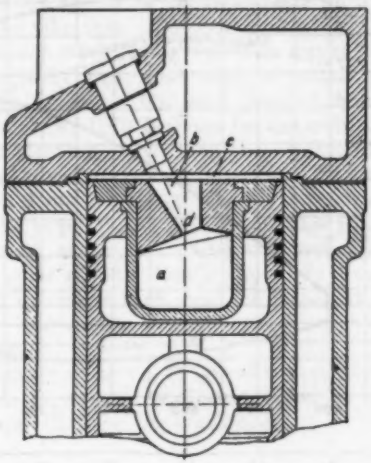


THE PRE-COMBUSTION CHAMBER OF THE "DEUTZ" AND "BERNA" ENGINES UNDER DAIMLER-BENZ PATENTS.

desirable condition to be attained. The injection pressure required for this design is consequently of a comparatively low order, and in actual practice is about 900/950 lbs. per square inch. It can now be clearly seen that at least for the essential atomisation and turbulence conditions the pre-combustion chamber design holds a big advantage over direct injection. It has been found, however, during long years of research work that a further and very important advantage is obtained, and that is that it enables a very much greater range of fuels to be employed than is possible with direct injection. A moment's consideration of the "combustion cycle" as described will make this point obvious. The low injection pressure is also an advantage in that it avoids undue wear and tear on the distribution pump and injector nozzles—important

points when considering general reliability and maintenance costs. It will also be evident that, as the primary ignition takes place inside a chamber completely isolated from the working cylinder, lubrication conditions are less likely to be affected than in the case of direct injection engines.

Finally, it will also be evident that the pre-combustion chamber design offers the experimental and research engineer a much greater scope for obtaining efficient results, in that it contains



THE "BOSCH-ACRO" HEAD WITH "AIR POCKET" SET IN THE PISTON.

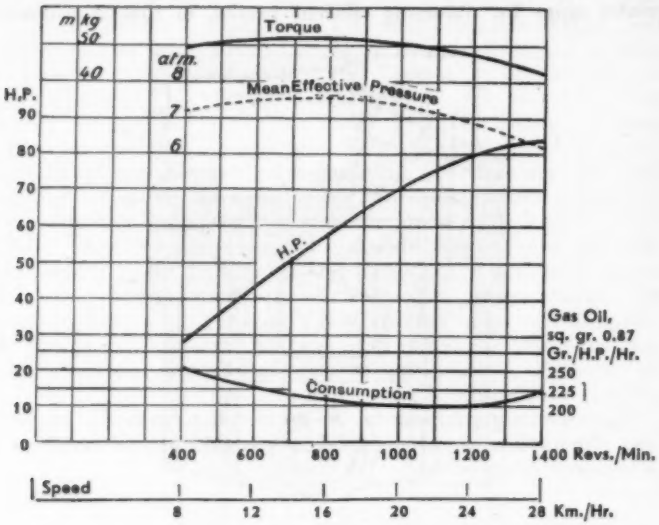
several elements which can be altered or varied in multiple combinations to achieve desired results, conditions which do not obtain in direct injection design. This is the secret of the very successful results obtained by the Mércèdes-Benz pre-combustion chamber engine, the patents of which are also incorporated in the Deutz and Körting engines.

It may be of interest here to describe the only example of a two-stroke opposed piston engine so far produced for transport purposes. Some of this type have been on test in this country.

The Junkers Two-stroke Opposed Piston Engine.

These engines are made in two sizes, one a two-cylinder with bore of 80 mm. and stroke of 300 mm., 3 litres capacity, 45 h.p. at 1,200 r.p.m., and the other a three-cylinder engine with a bore of

80 mm., stroke of 250 mm., 3·8 litres capacity, and giving 70 b.h.p. at 1,400 r.p.m. The former engine therefore gives 15 h.p. per litre, and the latter 18·5 b.h.p. per litre. These are, of course, of the direct injection type, the fuel being injected directly into the common compression space between the two opposed pistons. The injection pressure is 700 atm., or approximately 10,000 lbs



CHARACTERISTICS OF MERCEDES-BENZ ENGINES.

per square inch. The construction weight is from 7 to 8 kg./h.p., equal to from 15·4 to 17·6 lbs./h.p. In both cases the maximum compression pressure is 40 atm. (588 lbs.) and the maximum combustion pressure is 55 atm. (808 lbs.). Two of the smaller size of this engine have been tried out in this country by a very important 'bus undertaking, and their experimental department report that the M.E.P., as worked out from the Junkers instruction book, at 32 h.p. and 600 r.p.m. is 112 lbs. This can be considered very high indeed for this type of engine, but an official report in a German technical paper states that it is only 5·6 atm., equal to 82·32 lbs. They also report that the advantage of the opposed piston arrangement is that the cylinder pressures are balanced internally, and the crankcase can be made quite light. The

scavenging at low speeds is excellent, in fact, better than in a four-stroke engine, since the clearance volume is scavenged as well as the swept volume. The outside rods will not whip at high speeds as they are in tension throughout the cycle. One of the engines has run 6,000 miles without decarbonising, and the fuel consumption is from 12 to 14 m.p.g. The author has had no experience with these engines, but it appears to him that they have certain very pronounced disadvantages. The injection pressure of over 10,000 lbs. per square inch (obviously to obtain sufficient atomisation) would appear to be undesirable on a vehicle subject to continual road vibration. The heat generated in the combustion space, owing to each stroke being a working stroke for two cylinders, must be abnormally high and tend to make proper cylinder lubrication very difficult. For each pair of cylinders there are three big ends and two light bearings for the rods, thus multiplying lubrication considerably. Owing to the overcrowding of bearings on the crankshaft there appears to be no space for main intermediate bearings, which is not advantageous. It is reported that, after a certain time, the upper piston gets out of time with the lower one to a certain extent, and causes undue wear and deformation. The design of the engine requires that it should be abnormally high as compared with a normal type, and for transport this would not be attractive. Scavenging at high speeds must obviously be a difficult proposition.

The advantages appear to be greater h. p. capacity per litre, and elimination of valves, good scavenging at low speeds, and a balanced torque effort on the crankshaft.

Fuel Pumps.

For the successful performance of these engines, the most vital necessity is a reliable fuel distribution pump.

To enable a Diesel engine to run efficiently it was found necessary to produce a small, light, compact, fool-proof, and reliable piece of mechanism which would automatically feed the engine with the minute quantity of fuel oil required per cycle, and at the same time work at a very high pressure and speed, with no drip or leak, and be capable of being regulated both as to time of injection and quantity per injection, with the important parts easy of access and finally at a price which was not prohibitive. Needless to say, this was no easy task. The pump mostly in use to-day was originally devised by the Acro Company, of Kussnacht, and the patents were later acquired by Robert Bosch, of Stuttgart. Bosch expended a great deal of time and money on perfecting this pump and the machine now is a very wonderful and reliable little

apparatus. The author knows of one which has been in use continually on a Diesel lorry for two years, during which time the lorry has covered some 68,000 miles. Except for the accidental breaking of one spring due to a hidden fault in the metal, nothing has ever gone wrong with the pump. A 5-ton lorry running at about 1,300 r.p.m. consumes about 12½ lbs. of oil per hour. This comes to the minute quantity of 0·145 gramme of oil per cycle to be delivered. Considering the class of oil used and its proneness to creep, to do this without leak or drip needs a very accurate and reliable pump. The pump measures about 15×9×3 ins. and only weighs 29 lbs., *i.e.*, for a six-cylinder lorry engine of a capacity of 8½ litres.

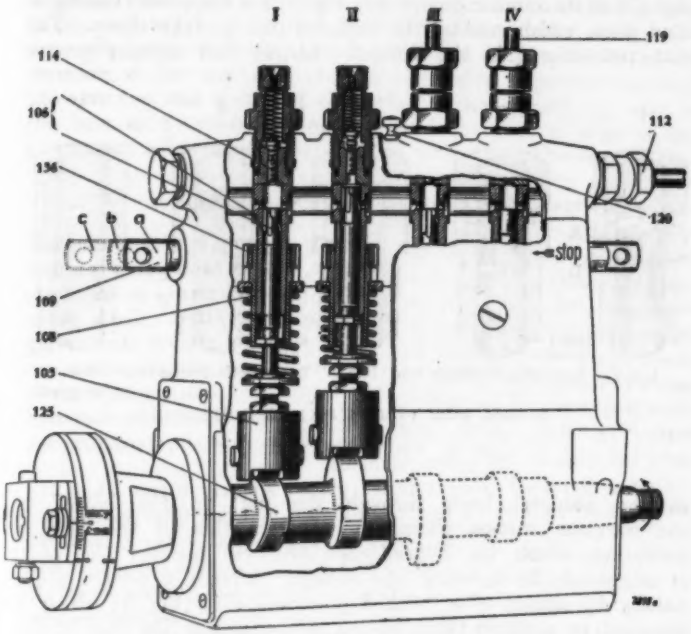
The description and action of the pump is as follows:

Construction.—The Bosch fuel injection pump is of the constant-stroke single plunger per cylinder type, so that each pump is a unit casing embodying normally as many pump elements as there are cylinders on the engine to which it is to be fitted. Each pump element (106) (see Fig. 1) consists of a highly ground steel pump barrel and a likewise highly ground steel pump plunger which is a piston fit for the barrel. The plunger is provided with a suitable guide and tappet roller (103) which bears on the cam (125). The discharge valve (114), fitted at the upper end of the barrel, completes the parts comprising the pump element.

Fuel is supplied from a tank (placed slightly higher than the pump), so that it flows easily through a suitable filter to the fuel inlet connection (112) and keeps the common suction chamber in the pump casing always flooded with clean fuel whence it can be readily drawn into the pump barrels of the various elements through the two small ports provided. As already mentioned, the plunger (106) always moves vertically in the barrel with a constant stroke, which in these models is 10 m.m. To enable the pump to vary the quantity of fuel delivered per stroke, the plunger is provided with a vertical channel (see Fig. 2) extending from its top edge (A) to an annular groove (the upper edge (B) of which is formed as a helix) a little way down the plunger length. External means (108 and 109, Fig. 1) are provided whereby the plunger can be rotated slightly in its barrel while working.

Operation.—Fig. 1 shows a section of a Bosch fuel injection pump, Model PE, for a 4-cylinder engine such as is used for vehicle work. Pump element I is shown at the bottom of its suction stroke when the two small ports are open through which fuel has already been drawn, thus filling the pump barrel. On the next up or delivery stroke (pump element II., Fig. 1), the plunger displaces fuel back through the two small ports until its top edge (A) (Fig. 2) covers them,

so that the remaining fuel is pressed out through the delivery valve (114), *via* the connecting piping to the nozzle in the engine cylinder. From this, it will be readily seen, that since the plunger



SECTION THROUGH 4-CYLINDER PUMP.

103 = Plunger Guide and Tappet Roller
106 = Pump barrel and plunger
108 = Control sleeve
109 = Control rod
112 = Fuel Inlet Connection
114 = Delivery valve
119 = Fuel discharge connection
120 = Lubricating oil gauge rod
125 = Camshaft
136 = Control toothed quadrant

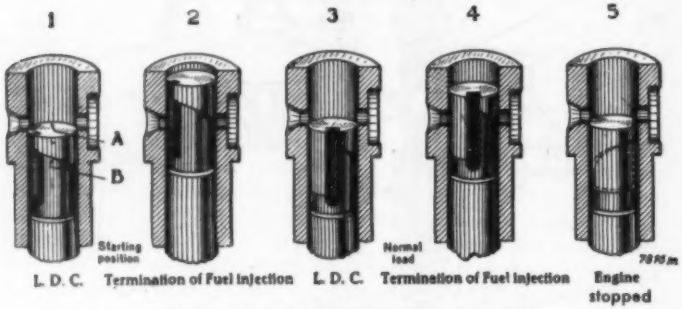
Note:

Pump Element I is shown on Suction Stroke i.e. Control Rod at (a) = Engine in starting position
Pump Element II is shown on Delivery Stroke i.e. Control Rod at (a) = Engine in starting position
Pump Element III is shown on Suction Stroke i.e. Control Rod at (b) = Engine at normal load
Pump Element IV is shown on Idle Stroke i.e. Control Rod at (c) = Engine stopped

FIG. 1.

is of constant stroke, its top edge will always cover the ports in the pump barrel at the same position of the cam rotation, so that the commencement of fuel injection at the nozzle will always

be the same relative to the position of the engine crank. As long as the ports are kept covered by the plunger, the pump will continue to inject fuel at the nozzle, but reference to 2 (Fig. 2) will show that before the plunger reaches the top of its stroke, the helical edge (B) of its annular groove (see Fig. 2) has uncovered the right-hand port, which enables the enclosed fuel to take the path of least resistance (*via* the vertical channel and annular groove



BARREL WITH VARIOUS PLUNGER POSITIONS.

FIG. 2.

in the plunger) back through the port in the barrel to the common suction chamber. The position of the plunger stroke at which the helical edge (B) will uncover the port, is adjustable by rotating the plunger through a certain angle axially by means of a toothed quadrant (136) (Fig. 1) which is clamped to a sleeve (108) having slots engaging the lugs of the plunger at its lower end. The toothed quadrant (136) meshes with a rack provided on the control rod (109), which embraces all pump elements in the unit and is externally connected to the governor, or other control, by links.

Anti-dribble device.—When the helical edge (B) of the pump plunger uncovers the port in the pump barrel near the end of the delivery stroke, the pressure of fuel is immediately reduced so that the delivery valve at once drops on its seating, thus cutting off communication between the pump and the nozzle until the next delivery stroke takes place. In coming to its seat to act as a non-return valve, the delivery valve is, however, made to perform the other highly important function of pressure pipe release. This double function is obtained by means of the novel but entirely simple construction of the delivery valve unit, and reference to

Fig. 1 will show that it is an ordinary mitre-faced valve with a long cylindrical guide which has a circular groove cut in it, dividing the guide into two parts. The lower part has a small vertical tunnel bored in it communicating with a horizontal boring in the groove. The upper part of the guide forms a small solid piston, which is a highly ground plunger fit for the valve seating also internally ground. When the pump is on its delivery stroke, as the pressure of the fuel rises, the delivery valve is pushed up until pressure fuel can escape through the vertical tunnel (by way of the horizontal boring and groove) past the bottom edge of the piston-like upper part of the guide over the valve-face to the nozzle. Immediately the pump plunger releases the pressure in the barrel, the delivery valve (under influence of its spring and the great difference in pressures between the pump barrel and the delivery pipe) proceeds to its seat, causing the small piston part of the guide to sweep down the valve seating with a plunger action, thus increasing the space in the delivery pipe (by an amount equal to the volume of the small piston part of the valve guide) before the valve actually seats itself. The effect of this increase of volume in the delivery pipe system, is of course, that of suddenly reducing, almost to atmospheric pressure, the pressure of the fuel therein so that the nozzle valve in the nozzle can "snap" to its seat, thus instantaneously terminating the spray of fuel in the cylinder, entirely without "dribble."

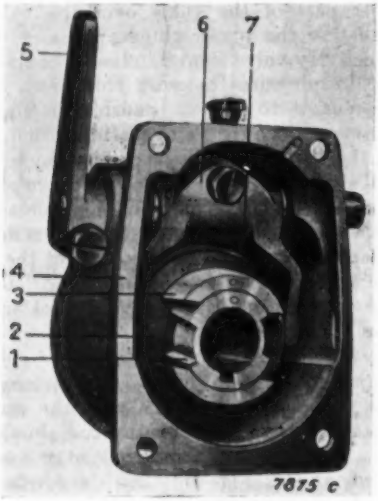
Control of output.—The word "stop" and an arrow engraved on one end of the pump casing, in line with the control rod (109), serve to indicate which way the control rod should be moved to stop the engine. A pump element at no output or "engine stopped" position is shown at IV. (Fig. 1), when the control rod (109) will be at (c) and the vertical channel of the pump plunger will be opposite the right-hand port in its pump barrel, as at (5) (Fig. 2), so that even if the engine is moved no fuel will be pumped.

When the engine is to be started, the control rod (109) is moved over from the stopped position (c) to the starting position (*a*), during which it travels about 25 m.m. The elements at I. and II. (Fig. 1) are shown at maximum output or engine starting, when they are capable of pumping more fuel than normally required with the engine at full load. This condition is generally required at starting to facilitate priming of the fuel pressure piping, etc., so that the engine will start readily. Thus, to prevent sooting up of the engine, care should be taken to make it impossible to adjust the pump to maximum output while the engine is running.

At III. (Fig. 1) the pump element is shown at normal output or engine running at normal load, when the control rod (109) will be

at (b). The actual position of the control rod at normal load can only of course, be found by experiment on the particular engine concerned.

The control rod (109) can be connected to the governor at one end and to the hand control or accelerator at the other. In linking these up, however, care should be taken that no transverse or rotational forces are transmitted to the control rod, which might be hindered or even jammed in its guide with resultant faulty control of the engine.



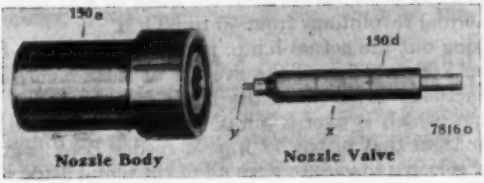
INJECTION ADVANCE DEVICE.

1 = Splined cone
2 = Splined bush
3 = Half coupling paws
4 = Housing
5 = Adjusting lever
6 = Adjusting stirrup
7 = Clamp

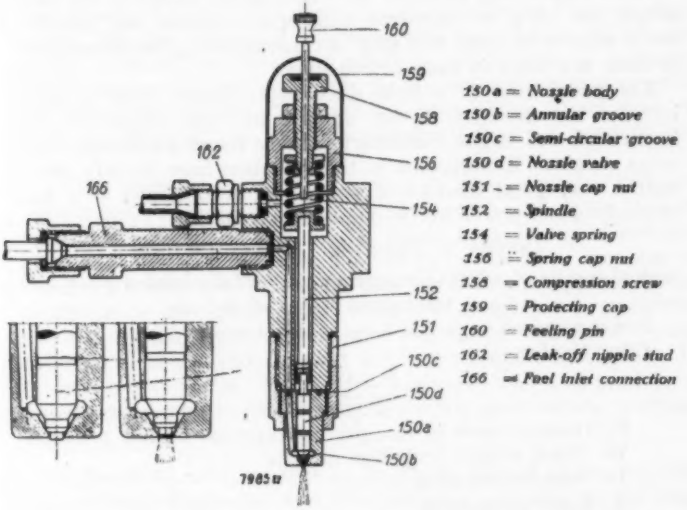
FIG. 3.

Injection advance device.—To further facilitate starting and to enable the engine to use the most favourable instant of fuel injection it is often desirable to be able to vary the commencement of injection. This variation is provided for in a neat manner by the Bosch injection advance device (Fig. 3) which is recommended especially for high-speed engines for commercial vehicles, etc. By means of this device it is possible to advance the moment of injection up to 8° measured on the pump shaft while the engine is running.

Construction and operation.—The adjusting lever (5) is connected by a small shaft and fulcrum with the stirrup (6) carrying a loose clamp (7) between the collars of a female splined bush (2). The bush (2) is a sliding fit on the two paws of the half-coupling (3) whilst in its splined bosom it carried the male splined cone (1) in which the pump shaft is fitted. It will be readily seen that by moving



the adjusting lever (5), whilst the engine is running, the bush (2) is caused to slide longitudinally along the paws of the half-coupling (3), so that by the action of the helical splines upon one another an angular displacement takes place between the pump shaft and the engine shaft.



NORMAL BOSCH FUEL INJECTION NOZZLE HOLDER MODEL PDH1/1z.

B.H.P. per Litre Capacity.

With regard to the b.h.p. developed per litre capacity, it is generally assumed that these Diesel-type engines are on the low side as compared with petrol engines.

Some official tables taken from one of our best-known motor papers, dated January 1, 1929, were consulted and from those tables four of the best-known heavy type lorry engines selected. The capacities in litres varied from 6·6 litres to 8·37 litres, and the b.h.p. at normal revolutions from 50 to 60 h.p.

On working out the actual b.h.p. per litre it was found that this varied from 5·97 to 8·6, and the average of these comes to 7·45.

This is actually lower than the figure for the heavy Mercedes Benz engine, which is over 8 b.h.p. per litre, and some 32·28 per cent. lower than that of the 77 h.p. Mercedes Benz engine.

The four selected machines were all of the 6 and 7-ton lorry type, the same as the Mercedes heavy machine.

As a matter of comparison, the highest figures found, those of two bus engines, one English and one American, both of which gave 17 b.h.p. per litre running at 3,000 r.p.m. They were six-cylinders. The only Diesel engine which gets anywhere this high figure is the opposed piston two-stroke engine already mentioned, and this gives over 18 b.h.p. per litre capacity, at a lower speed.

These figures help to offset the slight disadvantage of the extra weight per b.h.p. as compared with petrol engines, and therefore are of interest to those who may be contemplating the manufacture of these machines at some future time.

The possibilities of a light duty supercharger, used solely to increase the quantity of air, applied to these engines is very important, and might counteract entirely the disadvantage of the extra weight. Experiments in this direction have already proved that a very great increase of power can be obtained at a small expenditure of power for the supercharger itself.

THEORY v. PRACTICE. DIESEL ENGINE.

Actual results of a 200-mile journey with a fully loaded 5-ton lorry, *i.e.*, a total gross weight of 10 tons.

Power required to propel a car on level roads:

Using the formula

$$\frac{F. \times W. \times D.}{33{,}000 \times T.}$$

F. Tractive force in lbs. per ton (approx. 50 lbs. per ton).
W. Total weight propelled in tons.
D. Distance travelled in feet.
T. Time in minutes.
Gross load approx. 10 tons.

We have then

$$\frac{50 \times 10 \times 200 \text{ m.} \times 5{,}280}{33{,}000 \times 10 \times 60}$$

This works out to 26 h.p. as the average power exerted. For 10 hours this comes to a total of 260 h.p.-hours.

The fuel oil actually consumed was 14 gallons, equal to 120 lbs. Theoretically, at 100 per cent. value, 1 gallon of this fuel oil should produce 60 h.p.-hours. Fourteen gallons should produce 840 h.p.-hours, if we could obtain the whole of the heat value from the oil.

We do actually obtain 260 h.p.-hours, which is equal to 30·9 per cent. of theory. But the formula is for level roads, thus we actually do obtain well over 30·9 per cent. thermal efficiency, and the figure of 36 per cent. stated by the makers is therefore fully warranted, allowing as it does only 5·1 per cent. extra for hills, uneven road surfaces, stopping and starting, and low gear work in heavy traffic in London.

So that we have here proof enough that taking petrol at its present price, and Diesel or fuel oil at about 4½d. per gallon, the actual economy produced by running these engines, as against a petrol engine, is over 86 per cent. In hard cash, one can say that the comparison is as 5s. is to 38s. This is, of course, on fuel alone. When we consider the time saved by quick starting (which in a year's work amounts to a very considerable figure), high average speed, less gear changing, less wear and tear due to the steady piston pressure, less wear on tyres, no delays due to auxiliary apparatus, and general reliability, we can say without exaggeration that the total running costs cannot be much over 50 per cent. of that of a petrol vehicle, and it is doubted if they will reach 60 per cent.

At the moment, as we have to import these machines and the duty is 33⅓ per cent., naturally the first cost is well above that of home-made machines, and thus it comes to a matter of mileage as to whether the proposition is a paying one or not. One user is running 200 miles per day for five days per week, *i.e.*, approximately 50,000 miles per annum, and, of course, is getting a wonderful result. Anything over 25,000 miles per annum will show a very satisfactory result, and therefore for 'bus transport it is ideal. It is therefore clear that for the manufacturer who can produce a satisfactory engine in this country there is a great harvest waiting.

Fuel.

On March 15, 1912, a paper by Dr. Diesel himself was read to the Inst. of Mech. Engineers, and the following extracts are of considerable interest:—"It has been proved to be a most reliable

engine when properly built, the working of which is quite as safe as that of any other system of prime mover, and in general it is even more simple, since it does not require any auxiliary apparatus, and since the fuel in its natural and original form without having previously undergone any transforming process is directly converted into work in the cylinder of the engine. In 1897, at the Augsburg works, numerous engineering experts expressed the opinion that it gave better heat utilisation than any known kind of of heat engine. To-day (1912) the thermal or indicated efficiency reaches 48 per cent. in this engine, and the effective or brake efficiency reaches in some cases 35 per cent. of the heat value of the fuel." (These figures were challenged by Mr. Dugald, who said that it was impossible to get more than 39 to 40 per cent. indicated efficiency, and that 48 per cent. was erroneous.)

Dr. Diesel further stated that "any considerably higher efficiency in the process of transforming heat into mechanical work is not obtainable . . . . it is therefore the simplest and at the same time the most economical prime mover. These two facts explain its success. It lies in the new principle of the internal working process, and *not* in constructional improvements or alterations of older types of engines . . . . it has solved the problem of using liquid fuel for power production in its simplest and most general form, and has doubled the resources of mankind as regards power production."

Dr. Diesel's engine evidently used the crude oil as it came from the wells, and also used compressed air injection. With the engine we are now discussing neither of these conditions prevail. The fuel in most general use to day is either gas oil, solar oil, fuel oil, or so called Diesel oil, otherwise distillate oils with a much higher flash-point and therefore less dangerous, and furthermore leaving the light fractions still available. A specification of the oil generally used to-day in these engines is as follows :—

Sp. gr. at 60° F.	0·875
Flash-point, not under	150° F.
Pour point	30° F.
Water, not exceeding	0·05 per cent.
Sediment	0·012 ,,
Ash	0·005 ,,
Sulphur	0·850 ,,
Calorific value	19400/19600 B.Th.U.
Viscosity Redwood No. 1	116 sec. at 40° F.
	75 ,, 60° F.
	60 ,, 75° F.
	45 ,, 100° F.

The engine will however run on a great variety of hydrocarbons such as furnace oil, solar oils, tar oils, and in fact any of the heavy oils that can be made to run through the pump. Even a highly viscous oil such as heavy lubricating oil can be used in an emergency.

Gas oils and solar oils both possess high calorific values, and on account of their freedom from water, ash and asphaltum they form ideal fuels for these machines.

These engines are sometimes called "crude oil" engines. They will certainly run on crude oil, but this crude requires careful examination before it can be considered suitable for internal combustion engines. It often contains water, sand, leaves and similar mechanical impurities, and generally possesses a low flash-point. It should be carefully filtered and settled before use in this class of engine.

This oil has been used in these transport engines simply because it happens to be the oil supplied in great quantities generally for marine and stationary Diesel engine work; but as the conditions for transport are vastly different, it appears to the author that there is possibly a field for research work here to produce a fuel oil for this type of engine which will emit a non-smelling exhaust without losing heat efficiency, or, alternatively, to design an absorbent filter which will effect this result. The smell at present *is not any worse than a petrol exhaust*, and in fact is far less dangerous, but it is so different and distinct from that of petrol exhaust to which we are all used that people notice it more. This applies to vehicles standing with the engine idling. When running full out with load, the exhaust is quite clear and sweet. Idling conditions have always been the most difficult part of this engine, both as to noise and smell, but research work during the last six months has now resulted in a nearly perfect engine, and quite comparable to our best petrol engine.

Another point to be considered is—what is to become of the surplus petrol when these engines come into general use? There is plenty of time to consider this problem, and it is probable that our industrial chemists will find a good use for it somewhere, and in doing this they will be doing a great service by satisfying our philanthropic friends that products from both ends of the distillation scale are in demand, and thus avoid making one end pay for the other, by raising the price of the one most in demand. The author is constantly being told that as soon as these machines get going the price of the fuel oil required will be raised. There are several answers to this. The engine will run nearly equally well on about five different grades of oil. Some of these are in competition with coal. Others are used in great quantities by ocean liners. The s.s. "Augustus," for example, uses in one day about the same quantity of oil as a five-ton lorry would use in nine years running 140 miles per day. If one-third of all the heavy lorries in this country were using heavy oil, the amount used would not affect the imports more than about 3 to 4 per cent.

But the best and most satisfactory solution is the opportunity for our home-produced fuel from the new low-temperature processes, and the author hopes that in the near future a really good fuel will be available from this source, another good opportunity for our chemists to work on. Quite apart from the economy point of view, other great advantages of using heavy oil are entire freedom from danger of fire (this being especially important when considering passenger transport), elimination of tiresome restrictions such as those now in operation when storing petrol, greater mileage capacity per vehicle (approximately 100 per cent.), and therefore less time occupied in filling up tanks, less time required for starting up, and no time lost in warming up engine and radiator water, and the fact that the engine will run on so many different grades of oil that it need never be in difficulties for want of fuel (something between paraffin and tar oils can always be produced), and finally a reduction in insurance premiums for both vehicles and garages if the other philanthropic branch of the community can be convinced of its safety.

Exhaust Fumes.—A Gas Oil of 0·876 Sp. Gr. at 15° C. with a heat value of 19,602 B.Th.U. upper and 18,342 B.Th.U. lower, gave the following exhaust gas analysis :—

Revs.	Capacity.	CO_2%	O_2%	CO%
400 ..	21·8 ..	9·0 ..	9·7 ..	0·3
800 ..	47·6 ..	9·2 ..	7·6 ..	0·2
1200 ..	68·8 ..	10·0 ..	6·2 ..	0·0

Temp. 22° C. Barom. 740.

It is of considerable importance to note that at 1200 r.p.m. there is no carbon monoxide present in the exhaust gases. Assuming this is a typical analysis, the results are much better than are obtained on the average petrol engine.

Asphaltic base oils generally are not so desirable as paraffin base oils for the production of fuel oils for these engines, owing to the danger of coke formation on the pistons and exhaust valves. The coke value should in no case exceed 5 per cent. and the soft asphaltum value 10 per cent. During the period that these engines have been running in this country no trouble has been encountered either from sump dilution or the formation of carbon, one machine having run over 40,000 miles mostly with a full load during this time. This is due to the perfect combustion.

An experiment with a supercharger fitted to one of these engines gave the extraordinary result of increasing the power by nearly 100 per cent. (a normal 77 H.P. engine gave 150 H.P. on the brake), while at the same time the consumption was 20 grammes less per B.H.P. hour. It is evident that the high temperature of compression, combined with a large excess of air at the moment of fuel injection are very highly favourable to perfect combustion.

In actual work on the road the advantage of the Diesel is very apparent. It can safely be said that it is always at least "one gear better" than a similar petrol engine. This is due naturally to the longer and steadier period of expansion on the working stroke, this being similar to the steam engine stroke. The engine is extraordinarily flexible and has fine acceleration. It is a fascinating engine to drive, and if on pneumatics it is no more tiring to drive a 5-ton lorry than it is to drive a small petrol car. On one occasion the author drove 209 miles with a 5-ton load in 9 hours 20 minutes actual running time, this journey being from Aintree to Mile End Road, London. The consumption was 14 gallons of gas oil, which works out at over 16 net ton miles for the sum of 1d.

There are perhaps some 20 to 25 of these machines running in this country to day. All of these are of the heavy type of 5/6-ton lorry and a few of 10/12-ton lorries. Up to this date no passenger vehicle has, as far as the author knows, been run here. Experiments have been carried out, however, during the last 12 months on the Continent with a view to the production of a high-speed engine which would satisfy the exacting requirements of the passenger vehicle.

With a lorry, within limits, the exhaust fumes are not of great importance, and idling conditions do not matter a great deal. With passenger work, however, the conditions are vastly different and these two points are of vital importance. The engine referred to is a 6 cylinder, 77 B.H.P., 7 litre machine, running normally at 1650/1700 r.p.m. It is a Mercedes Benz production with their pre-combustion chamber design. The vaporiser has been so designed and improved that the idling and exhaust have been brought to a state of perfection which enables the engine to compare very favourably with the modern petrol engine, and there is reason to believe that when this engine is actually in production, that its use in public service would attract no more attention than a normal petrol engine.

Another firm has been experimenting on a small car engine, and has actually produced a 4-cylinder engine, running at 2000 r.p.m. The bore is 2 in. and the stroke $4\frac{3}{4}$ in. The treasury rating would be 7 h.p. for tax purposes, but this little engine gives actually 25 h.p. on the brake. It is actually pulling an old car weighing $1\frac{1}{2}$ tons. The engine is not in production and certain difficulties have yet to be got over, but it is the author's opinion that before long a suitable engine for cars will be produced. The most difficult point, that of designing a pump to supply only the minute amount of oil required per cycle has been achieved.

It is reported that a single cylinder motor cycle engine, in Austria, developing 6 h.p. has been produced, and running at 2400 r.p.m.

Undoubtedly, unless some radically new and unexpected source of power for transport is suddenly produced, the development of the compression ignition engine in the next few years will be both fast and interesting.

The author ventures to predict that the design of these engines will tend to settle down to multi-cylinder machines with 6 or 8 cylinders, of the pre-combustion chamber type, with reasonably low injection pressures (not over 1000 lbs. per sq. in.) overhead valves, four stroke cycle, with either mechanical or compressed air starting mechanism, and probably giving about 12 h.p. per litre capacity at 1600 r.p.m., weighing perhaps 12 to 14 lbs. per B.H.P., and with a life of perhaps 40 per cent. more than that of a petrol engine.

The principal reasons for this prediction are that the 4-stroke engine has been for years adopted in preference to the 2-stroke, and this has been again upheld by the majority of the makers of Continental Diesel engines during the last ten years. Possibly this is partly accounted for by the fact that as the whole motoring industry for over 30 years has been trained to this type of engine, it is preferable to keep to it rather than bring in something which they are not trained to. From a technical point of view it would appear that although the 2-stroke engine should produce twice the power at equal revolutions without much added weight, scavenging, heat and lubrication conditions, seem to have kept it out of the market.

With the fuel charge accurately measured for each cylinder as in the Diesel engine, the great advantage of multi-cylinder engines is very obvious, especially when added to the steady torque advantage. As already explained, the great advantages of the pre combustion chamber design so outweigh any disadvantages that it may have, more especially when considering the wide range of fuels and the high degree of atomisation secured, that it is reasonable to presume that this design will predominate.

With regard to weight, it is also reasonable to presume that the metallurgists will help considerably to lower the present weight, and, indeed, this is actually happening at the present time.

Recent experiments lead us to expect that a reliable compressed air or even a mechanical starter may soon be produced to take the place of electrical starting, which involves the use and carrying of very heavy storage batteries.

The prediction of a longer life for these engines is based on the fact that owing to the constant pressure period and the resultant duration and steadiness of the torque effort, especially at partial

loads, and the better cylinder lubrication, and elimination of sump dilution, it is reasonable to assume a longer life. Actual results up to date tend to confirm this. A further point is that these engines produce the power required with considerably less revolutions, and therefore tend to have a longer life.

DISCUSSION.

The President said it would be a matter of common agreement that the members had heard a very important paper; and as there were present a number of guests, whom he cordially welcomed, particularly from the Diesel Engine Users' Association and the Institution of Automobile Engineers, he must ask members to confine their remarks within the smallest possible compass.

It was interesting to hear Major Goddard talk about the new omnibus in Sheffield. He had noticed in the *Times* a statement to the effect that features of this vehicle were: very low running costs of only one-sixth of those of the petrol-driven motor 'bus, using gas oil at 4½d. a gallon; high thermal efficiency and, perhaps the most important factor, the elimination of fire risks. It was creditable that the author had been concerned with such a vast development, especially seeing that it was likely that petrol engines would be taken out of the Sheffield omnibuses and Diesel engines installed. It was clear that the matter had been carried beyond the experimental stage.

He was inclined to go a stage further than Major Goddard had, and feel greater confidence that the time was coming when the compression ignition engine would monopolise heavy road transport. He asked members to think of its greater thermal efficiency, the wider selection of fuel possible, the simplicity of the design, the absence of carburettor, the absence of magneto, and, above all other things, the immense safety of it, and then it would be obvious that it was the engine of the future. And this prediction was even more certain in the case of aircraft.

He was more particularly concerned with Major Goddard's view regarding fuel, particularly in his references to the possible application of low temperature tar. He would like to ask the author whether he contemplated the use of tar as a whole, with its pitch and tar-acids, or the production of a neutral oil, free from acids; also what the price of the commodity was likely to be. In the case of petroleum it was different, because there was an extraordinarily wide range of potential fuels—everything from the topped oil downwards. At present, analyses showed that gas oil or solar oil was the ideal fuel. He was sure the members would be grateful for any information the author could give them as to

the utilisation of heavy residue oils. He was glad to note the statement that any of the heavy oils were likely to be satisfactory which could pass through the fuel pump. That was a comforting specification, and he recommended it pending the arrival of the time when it was possible to lay down criteria for the fuel for the Diesel engine.

Mr. James Kewley said he desired to add a few remarks to those made by the President with reference to fuel. From the author's paper one might conclude that the Diesel engine was like a very voracious animal which would digest fuels of any type, even heavy residual oils and tar oils, but it later appeared that as a matter of fact it might be described as having a tender digestion. Thus, in the specification given a low sulphur content was stated. It was, he thought, generally admitted that there was no necessity for setting the sulphur content of Diesel fuels at such a low figure; that such a figure would exclude many of the coal oils and shale oils which may be made in the future and even many of the existing petroleum distillate fuel oils.

With regard to the question of price, he said that Diesel engine users should not deceive themselves with the idea that they would obtain fuel at 4½d. per gallon or thereabouts; that such a figure was a bulk quotation and that if the fuel were to be distributed throughout the country as motor spirit is, something must be allowed for the retailers' profit and for the possibility that the Chancellor of the Exchequer would tax Diesel fuels as motor spirits if they were eventually used for transport purposes; that it must also be remembered that there were other users who were competing hard for such distillate fuels. The gas oil or distillate type was being used to a considerable and ever-increasing extent in the United States for domestic heating purposes and so forth. (N.B.—The so-called Furnace Fuel used in the U.S. is really a light gas oil.)

He concluded that, although gas oils would probably never reach such a high price as that of gasoline, in course of time the prices of these two commodities would certainly approximate to each other.

Mr. J. McConnell Sanders also wished to allude to the paragraph in which the author said that asphaltic base oils, such as Californian and Mexican, were not generally desirable. This fact—if it were a fact—had a significance which was farther reaching than at first might appear, because it was almost certain that the future supplies of Diesel fuel would be derived from asphaltic base oils. And if such oils were undesirable it must be considered

whether it would not be necessary to refine them considerably more than at present was the case, and that must naturally add to the cost.

The question of sulphur, which was raised by Mr. Kewley, was important. The speaker had known cases in which the exhaust valves of stationary Diesel engines had been cut badly by the sulphur in asphaltic base Diesel oils. It might, therefore, be necessary to remove or reduce that sulphur, and, as had already been mentioned, that would add to the cost.

Mr. O. Thornycroft said he had listened to this paper with much interest. What appealed to him particularly was Major Goddard's very apt description of the difference between the Diesel engine and the petrol engine. The petrol engine consumed all its air but not all its fuel, while the Diesel engine consumed all its fuel but did not use all its air. It was this feature of the Diesel that was the primary cause of its wonderful economy in fuel. There was, however, another aspect to this feature of not burning all the air. Since the quantity of air received from the engine was limited by cylinder dimensions it was clear that the Diesel must give less power than a petrol engine of the same size, unless supercharging was used. He would like to know whether the mean effective pressures recorded in the paper were observed by the author. He asked that question because the values seemed to be unusually high for brake mean pressures. The maximum value shown by the curve given in the paper, namely, 7½ atmospheres, was 110 lb. per sq. in., and for the type of engine to which the author referred this seemed an extraordinarily good figure. His own experience was that it was difficult to get, with clear combustion, anything like such a high brake mean effective pressure. If he (Mr. Thornycroft) was right in thinking that clean combustion could not be obtained with more than about 85 lb., possibly 90 lb., brake mean pressure, it left the petrol engine with an advantage of 40 per cent. or more. Even assuming there was no increase of weight due to the somewhat higher maximum pressures which existed in the Diesel type, the engine must weigh at least 40 per cent. more than a petrol engine of the same output, a serious matter in a passenger vehicle in which weight counted for so much. (Several well-known manufacturers now produce commercial vehicle petrol engines weighing no more than 10 lb. per B.H.P.) He agreed with the author that just as high speeds would eventually be obtained with the Diesel as with petrol engines.

He would like to raise the question of efficiency, as he thought Major Goddard had a little under-estimated the fuel economy of

present-day petrol engines. The best performance of the modern lorry or 'bus engine was about 0·5 lb. per brake horse power at full load. He admitted that, owing to the reasons given by the author, namely, that the petrol engine did not burn all its fuel, the average consumption was very much worse than the best represented by the figure given. The average consumption under favourable road service conditions was about 0·75 lb. for a modern petrol engine as against the figure given by the author for the Diesel engine of 0·44 lb. which was 200 grams per brake horse power. The advantage therefore in favour of the Diesel in fuel consumption was at least as 5 to 3. (Probably in many road service conditions the advantage would be as 2 to 1 in weight of fuel.)

He agreed with the author's view that the difficulty of lubrication (particularly of the piston) in a high-speed two-stroke Diesel was much greater than in the four-stroke type. We were much nearer to getting a fully satisfactory four-stroke engine.

Mr. A. W. A. Chivers referred to the experience of stationary engines, in which the Diesel Engine Users' Association were concerned, and in connection with the type of engine proposed for road transport, said that he thought many people would be wondering, quite apart from the comparisons which had been made between the heavy oil engine and the petrol engine, how such an engine would stand up, from the maintenance point of view, in ordinary day-to-day service. It may be thought that, from the relatively high speeds (he was referring to the rate of revolutions) of this type of engine compared with the relatively slower speeds of Diesel engines, which were more familiar to us in this country, that the question of maintenance might become a very serious factor. Of course, that was a point which had to be proved; but he was able to say that with regard to stationary engines the increasing of the speed, in which there had been a marked tendency during the last few years, had not brought with it an increase in maintenance charges. On the contrary, he thought he was right in saying that the development of high speed stationary Diesel engines had brought with it lower costs of maintenance. That might be due not inherently to the type of machine, but to the greater experience which had been gained, and the gradual development which had taken place to produce the modern type of engine compared with what Diesel engines were 20 years ago.

Points had been raised as to the classes of fuel oil which might be, and the classes which might not be, suitable for small engines such as that under discussion; and reference had been made to the serious drawback which might be experienced if the engine could not successfully use an asphaltic base oil. He thought he

might say that the general opinion with stationary engines in that connection is that soft asphalt is not detrimental, but that hard asphalt is prejudicial.

He had been particularly interested in the application of the engine to road transport, and one feature of its development in which he was interested was a comparison with the petrol engine, not only with regard to flexibility (which had been said to be as good as that of the petrol engine) but what might be regarded as its "responsiveness," or "liveliness" from the point of view of operating it in dense traffic. In the case of the petrol engine it will have been noted by most observers that, in cases where a low-grade petrol was being used, the trouble with a smoky and smelly exhaust was pronounced when the engine was idling, and when accelerating. He had been told that up to the present time the Diesel engine had that characteristic, which was rather a bad one. He did not know whether it was true or not, but it was reported in some technical papers not long ago that in some German towns in which the Diesel engine had been experimented with for town service, the effects of the exhaust were so bad and were thought to be so prejudicial that the authorities had all the vehicles removed from the streets. If that was a fact, it was, of course, sure to be a serious objection to town work. But one should not be disheartened over that, because it must be remembered that, in making a comparison with the Diesel engine, one was comparing a new type of engine with what could be now regarded as a more or less old and developed type of petrol engine; and he did not remember any case in which a new type of engine had sprung up for a particular use and where the prospects of the engine becoming successful were more pronounced than in this case. When one considered the great developments which had been made in the petrol engine, the perfection to which it had been brought and the work it had accomplished, great credit is due to the engineers who had designed the heavy oil type of engine to make it a probable successful competitor with the petrol engine. Whatever the characteristic of the engine might be, or what it might be developed into for town work, there would appear to be a large scope for it for lorry work, particularly in foreign countries, where the question of a smoky exhaust is relatively of little importance. He was at the moment particularly interested in that aspect of the question, and he would be most interested to watch the developments which were taking place in its application to that class of work.

Mr. W. J. Marshall said he would be sorry if anyone should leave the meeting under the impression that only German engines were available, as there were English High Speed Heavy Oil

engines actually ready to be offered for use for lorries or for other purposes of a similar nature. He wished to mention one with which he had been intimately connected. Messrs. Blackstone & Co., a firm associated with the group to which the speaker belonged, had had an engine in preparation for two years, which recently had been mounted in a lorry and run a large number of miles with the utmost success. The weight of the engine was about 28 lb. per horse power, and an important feature was that it was in no way indebted to Germany for any patents, either for the combustion chamber or the injection system. The injection system was Messrs. Blackstone's own patent spring injection, which has given such excellent results on their standard stationary engines and which proves to be an admirable system for the High Speed type of engine.

He recently had an opportunity of testing one of these engines on full load for 100 hours continuously on a brake—an exacting test for such an engine—which it had accomplished with full honours. At the end of the 100 hours, the engine was dismantled and found to be entirely free from carbon deposit. The fuel used on this test was a standard Diesel engine fuel oil.

The same engine had also undergone a long full load test on a very low grade Argentine fuel oil of high specific gravity and high ash and asphalt content, and had proved its capacity for operating satisfactorily on such oils provided that the injector nozzles were cleaned at more frequent intervals and attention were paid to the lubricating oil.

He had hoped to hear some authoritative pronouncement as to the probable effect on the prices of liquid fuels of a considerable extension of the use of engines burning heavy oils and a proportionate reduction of engines burning petrol. Can it be conceived that we would again have the conditions which existed about 30 years ago when petrol was a superfluous by-product to be got rid of at a low price ?

Mr. W. B. Rowntree asked for the author's opinion regarding the effect of atmospheric temperature changes on the functioning of the engines.

In view of the difference in Setting Point of the various Diesel Fuels available—ranging from below 0° F. to over 40° F.—was there any necessity for pre-heating the fuel in winter weather ?

In summer weather, of course, the pump action might be fairly constant, but any lowering of atmospheric temperature would, by elevating the viscosity of the fuel, tend to create an increased load on the pump.

What detrimental effect would that have on the running ?

Mr. E. L. Bass desired to ask about one practical point, namely, that of starting the engines. The author stated that compressed air and mechanical starters were being developed which would be an advantage in that electric starters with heavy batteries would be eliminated, but under service conditions it was necessary to have an alternative means of starting the engines. In the case of compressed air, receivers are frequently found empty and electric storage batteries may be run down for a variety of reasons. Therefore, it was essential that the engines should be capable of being started by hand and he would like to know from the author what were the possibilities of this being attained with the Mercedes-Benz engine, particularly in view of the fact that there were at least two British engines of approximately the same size and certainly of equal performance to the Mercedes-Benz engine, which could be started from cold by hand-swinging.

Mr. C. B. Wardman said he would like to support Major Goddard's point with regard to the desirability of paying attention to the low-temperature carbonization process. He had used one of the machines ; he put one of the vehicles into test in 1928, and, as members of the Institution probably knew, the test was awarded the Dewar Trophy, as it was considered to be the most meritorious performance in the Royal Automobile Club observed tests of 1928. He always had the bogie of the prices of oil to slay. The idea seemed to prevail that the prices between petrol and the heavy oils could be adjusted, and that the general application of the Diesel engine would bring about an increase in the cost of oil. He wished to say, emphatically, that that view was entirely wrong, and Major Goddard had given the meeting a proper line of direction, working on the basis of getting oil at under 4d. per gallon as a definite permanent proposition. Some time ago he inspected one of the low-temperature carbonization plants in Scotland, and spent two days at the retort, so that he might have first-hand experience of the product. He found that upwards of 30 gallons of oil could be produced from a very low grade coal, such coal as could be bought at about ten shillings a ton. He obtained specimens of the oil so that he could test it in his Diesel-engined lorry ; and he found that the oil was more suitable, and gave a better performance than did any other oil he had tested ; and he had been assured by the owner of the plant he investigated, that not only could 30 gallons of oil per ton be produced, but that the smokeless fuel obtained would more than pay for the initial cost of the coal ; in other words, that at 4d. per gallon there was a substantial margin for the operating of the plant. There was one other point he would like to speak about, namely, the flexibility of the machines. His

experience had been that, almost within the first 20 or 30 yards, he wanted to get from third into second and then into top gear; and in traffic, going round corners at low speeds, it was possible to keep on top gear, and have that same comfortable feeling that one had in a high-powered six-cylinder car.

Major Goddard, in reply, said he desired in the first place to make it clear that, as a Britisher, he would certainly like to see a British Diesel engine which would compare favourably with the engine he had been chiefly describing that evening. He had been collecting Diesel literature, in order to try and learn all that was going on in connection with the matter, and he had been compelled to realise that German engineers had got far ahead of the British engineers on the subject. If, as one speaker in the discussion had said, there was a British engine which could favourably compare with the Benz, he, the speaker, had not heard of it, and he would very much like to. If that engine had been on the road and had been reported upon, he, Major Goddard, would have known about it. Of course, if the tests were carried out on the bench, he was not likely to be able to so much as guess what was going on; he had not a chance. The engine to which reference had been made was said to weigh 28 lb. per brake horse power. That did not compare well with the Benz, which was 20½ lb., or the fast engine 16½ lb. The engine he referred to was the McLaren-Benz stationary engine, which was put into a lorry somewhere near Stoke-on-Trent. It weighed 43 lb. per brake horse power, and it smoked badly. People who knew little about such things had said to him that they had seen a lorry going through the town smoking like the chimney stack of a factory. He felt very hurt by those remarks, as he was a pioneer in the matter of the Diesel engine for transport on the road, and when people who did not realise it was a good engine made remarks like that it made him a bit tired.

He would like to see the Blackstone engine and have a trip in it, he would be among the first to rejoice that there was a British engine of such merit. At present, however, he had no knowledge of a British engine which could compare with the German product, simply because the Germans had got ahead of this country in that respect. It was the only engine he knew which could be put on a 'bus, the higesth test he knew.

With regard to Dr. Dunstan's question as to low-temperature tar oils, the author had in mind a neutral oil free from acids. The price was, naturally, difficult to estimate, but he hoped that it would at least compare favourably with the present price of gas oil and similar distillates.

He was now having tests made with creosote, and he would see that the Institution was informed of the results of those tests when they were completed. He could say, however, that any hydrocarbon which could be run through the Bosch pump could be burned in that engine. The only difficulty encountered was when heavy Mexican crude oil was used, which would not run in cold weather.

As to asphaltic base oils, he admitted they were more likely to give coke formation than others, but there was no reason why they should not be used.

Undoubtedly the prices of fuel would undergo a change of some sort, but in the meantime, while the Diesel engine was being developed there was a great chance for the transport people to take advantage of the price ; it would not be altered for some time. Then, he thought, there would be a gradual change. There was now a big chance for economy in transport.

Mr. Thornycroft had referred to the M.E.P., but he did not know from where he had obtained the figure of 7½, the actual brake M.E.P. was 97 lb., or a little over 6 atmospheres. The thermal efficiency of the engine, according to the designers, was 36 per cent. ; the best petrol engine was 23 per cent. or 24 per cent.

With regard to the question of maintenance, up to now there was an experience of 68,000 to 70,000 miles on one machine ; that was not a long time on which to judge, as machines went to-day, but from the experience of that machine and the tests it had gone through, it looked as if the Diesel engine would stand up somewhat longer than a petrol engine on equal wear and tear. But no reliable figures had been obtained, because it had only been 18 months at work.

With regard to the point raised as to the responsiveness of the engines in traffic, it was as good as a petrol engine, and in acceleration too.

The author then asked Mr. P. M. Sanders to give particulars of results he had obtained with a Mercedes-Benz-engined 'bus.

Mr. P. M. Sanders stated that during a test of the vehicle, using a Tapley performance meter, he had obtained readings indicating the accelerating power of the machine that compared favourably with a petrol-engined 'bus chassis which had a slightly larger engine and carried a slightly heavier total load. Actually the figures obtained on top and third gear were approximately the same, but the Mercedes-Benz engine was fitted with a governor which limited its speed to 1600 r.p.m. and, as it was otherwise capable of attaining higher speeds, its best prrformance was not ascertained.

Major Goddard, continuing, said that as to pre-heating the fuel, there was no need for that, except in the case of using very heavy stuff in cold weather. Then the fuel would have to be warmed up; but up to the ordinary fairly mobile fuel oil, even when the weather was freezing, it was possible to run the engine. He had not had to use pre-heating.

In regard to starting, he used a big electric starter, which meant carrying an extra battery, and that was a disadvantage to set against the many advantages. Starters had been tried experimentally, but the electric starter, properly looked after, had caused no trouble at all. The extra weight on the bus was about 112 lb. and that could not be avoided at the moment, because it was necessary to provide a heavy amperage to turn the motor over. Hand-starting with the machine was impossible because there was a pressure of 550 lb. If there were trouble in starting he would hitch on to another lorry for a few yards and then all would go well.

On the motion of the President, a hearty vote of thanks was accorded to Major Goddard for his excellent paper and the meeting terminated.

Mr. J. L. Chaloner subsequently wrote :—

Major Goddard's paper deals with the Mercedes-Benz engine only, and the discussion must therefore, be in the nature of a comparison of the Mercedes-Benz with other unmentioned makes.

A far better review of the present situation would have been for Major Goddard to confine himself a little more closely to the title of his paper and deal at greater length with as many of the existing high speed engines as possible. One would then have been in a better position to draw conclusions as to the present stage of development of the high-speed light-weight Diesel engine in general and the relative performance of each type in particular.

The subject divides itself automatically into the headings of technique and economics.

Technique.—The different categories enumerated by Major Goddard in his classification are wrong and introduce confusion. For instance, what difference is there between the category "Diesel Engines without Air Compressors" and "Direct Injection"? At this stage the importance of the subject merits very much more care being exercised in reviewing the high-speed Diesel engineering fundamentals. It was, in his opinion, very essential, particularly before a body as represented by the members of the Institution of Petroleum Technologists. He did not suggest that in dealing with the nomenclature, Major Goddard should have gone as far as he

(Mr. Chaloner) had in his paper on High-Speed Oil Engines,[1] but treatment of the subject on similar lines would certainly have been more instructive.

Major Goddard being connected with the Mercedes-Benz would naturally give preference to his own engine, but one very much questions the wisdom of the dogmatic and even prophetic statements that the future high-speed light-weight Diesel engine "must settle down to the pre-combustion chamber type with reasonably low injection pressures of not over 1,000 lb. per sq. in., overhead valves, 4-stroke cycle and mechanical air compression or starting mechanism." The cylinder capacity and weight as quoted would indicate that he is qualifying this prediction, with reference to the heavier lorry type. At the same time, even with this restriction, he entirely disagreed with the author's views on the exclusive merits of the pre-combustion design.

It was his considered opinion that if the pre-combustion design is effective, then it is likely to be more so with a slow speed engine, rather than with a high speed engine. The results of experience are usually found not only in the various steps during the development, but also in the state of the art as represented by current practice. From that point of view it is quite definite that the symetrical simple form of combustion chamber has stood the test of time, and proved superior in every respect to those attempts made from time to time to introduce the dual chamber construction. Nor has Major Goddard shown with his performance figures that he can substantiate his claim. In Table I the Mercedes-Benz six-cylinder 8·55 litre engine (105 × 165 mm.) is quoted as developing 70 h.p. at 1,300 r.p.m., whilst the performance curve gives 80 h.p. at 1,200 r.p.m. with a corresponding mean effective pressure of 6·86 atmospheres (97·75 lb. per sq. in.). The curve also shows a maximum mean effective pressure of 7·65 atmospheres (108·5 lb. per sq. in.) and he agreed with one of the speakers that this figure was too high.

He suspected that there was a misunderstanding of the figures, and it would certainly be interesting to have a corrected curve based on the rating mentioned on the table, i.e., 70 h.p. at 1,300 r.p.m. This additional chart should also show the mean indicated pressure of the bench test records in addition to the mean effective pressure.

Another point of interest is the departure from conventional characteristics of high-speed Diesel engines, such as represented by the M.A.N. type (Fig. 1). His observation had been that the

[1] "High-Speed Oil Engines," by J. L. Chaloner, Inst. of Auto. Eng., February, 1923.

maximum mean effective pressure was to be found at a speed slightly higher than that at which the fuel consumption was at a minimum.

He desired to draw a few more comparisons between the Mercedes-Benz and the M.A.N., which latter he ventured to suggest has proved very successful. Taking the aggregate horse-power of all engines put into commercial use (not necessarily confined to lorry

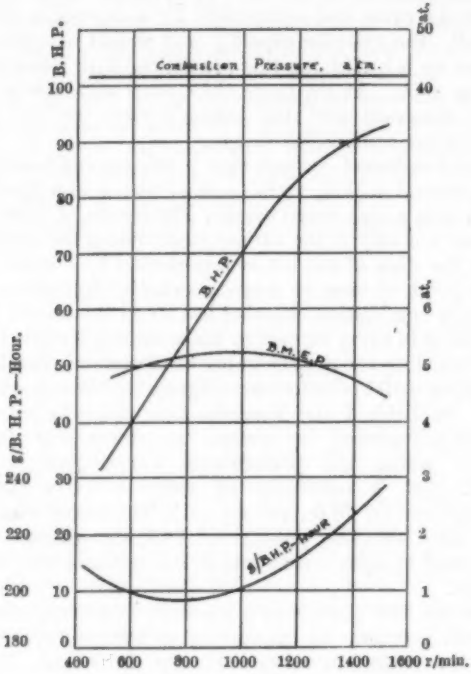
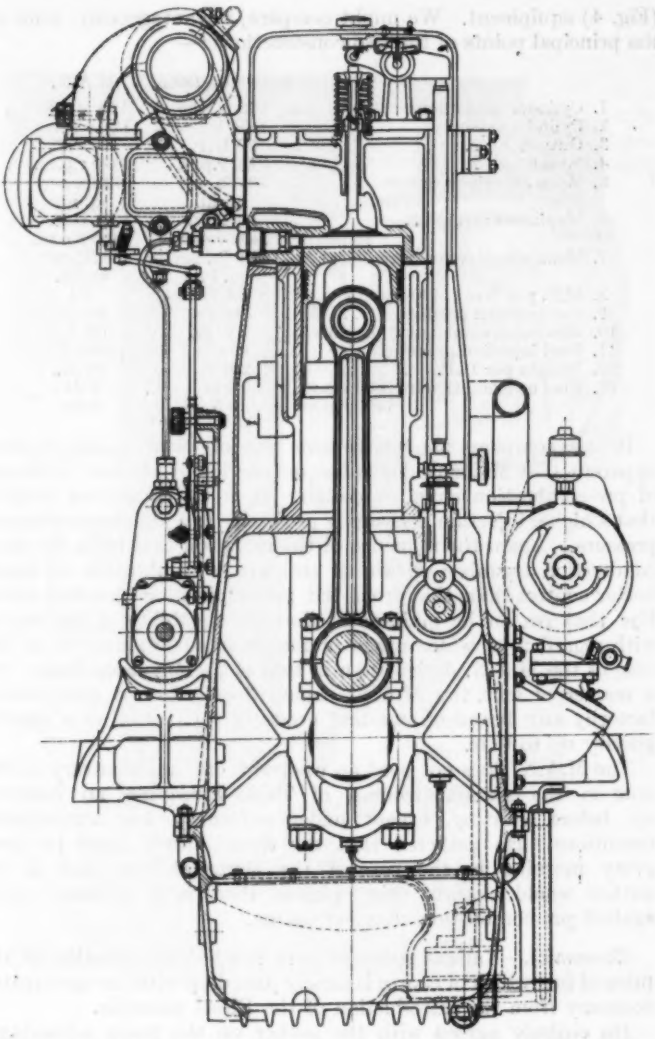


FIG. 1.

drive), the M.A.N. type has established itself to a greater extent than any other make in the world. This position of the M.A.N. warranted some reference by the author, who confined himself to a sectional view of an engine of a very antiquated construction. He therefore illustrated a section of a modern type (Fig. 2) and also an external view of the six-cylinder (Fig. 3) and the four-cylinder



Vertical Cross Section through M.A.N. type Light-weight High-speed Lorry Diesel Design.

FIG. 2.

(Fig. 4) equipment. We might compare, advantageously, some of the principal points of the two constructions :—

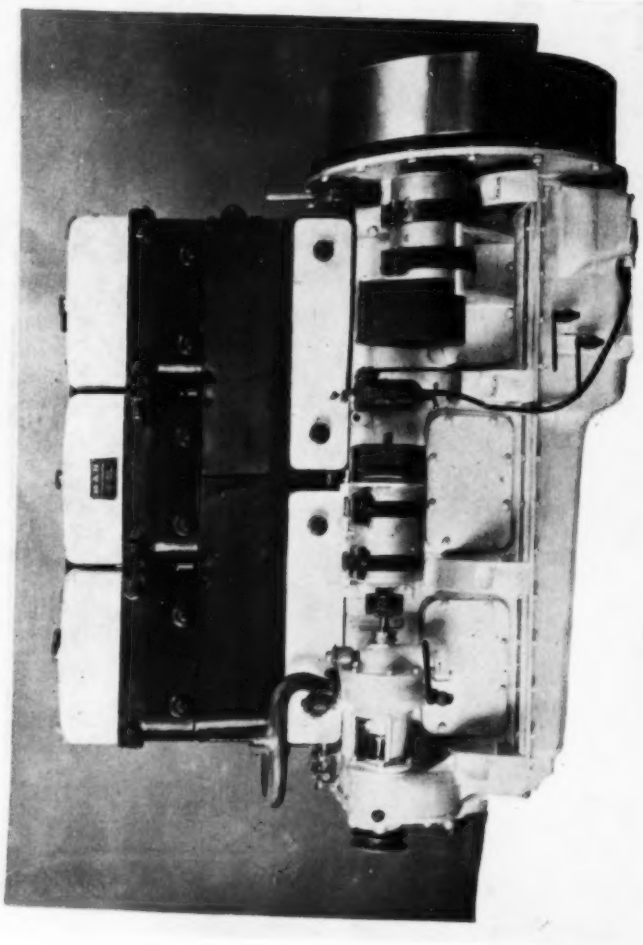
	Mercedes-Benz.	M.A.N.
1. Cylinder dimensions	105 × 165 ..	120 × 180
2. Cylinder capacity	8·55 litres ..	12·15 litres
3. Output	70 H.P. ..	70 H.P.
4. Speed	1000 r.p.m. ..	1000 r.p.m.
5. Mean effective pressure	105 lb. per sq. in. ..	74 lb. per sq. in.
6. Maximum rating	84 H.P. 1400 r.p.m. ..	90 H.P. 1400 r.p.m.
7. Mean effective pressure	88·2 lb. per sq. in. ..	68 lb. per sq. in.
8. H.P. per litre (1400 r.p.m.) ..	9·8 ..	7·4
9. Compression pressure	500 lb. ..	360 lb.
10. Maximum combustion pressure ..	640 lb. ..	595 lb.
11. Fuel injection pressure	850 lb. ..	4300 lb.
12. Weight per H.P.	20½ lb. ..	27 lb.
13. Fuel consumption at 1000 r.p.m. ..	0·45 ..	0·44
1400 r.p.m. ..	0·5 ..	0·49

If one compares the above two sets of data, it will become apparent that Major Goddard has not made out his case in favour of pre-combustion chamber design. It is his considered opinion that a higher injection pressure is preferable to a higher compression pressure. Again the influence of the radiation heat from the plain combustion chamber surface on the rate of combustion, is under better control than that from the pre-combustion chamber walls. For that reason he maintained that the flexibility of the engine with regard to a wider range of fuel is more pronounced in the case of the M.A.N. design than in that of the Mercedes-Benz. As a matter of fact, the M.A.N. engine does consume quite satisfactorily any brand of standard grade Diesel fuel oil of a specific gravity up to 0·91.

The M.A.N. does not need an electric torch, and contrary to the note in the remarks column of Table I requires no warming up before starting, except under extremely low atmospheric conditions. He gathered that the electric torch must be used every morning in the case of the Mercedes-Benz, and if the author would confirm this opinion, then it is another point against pre-combustion chamber design.

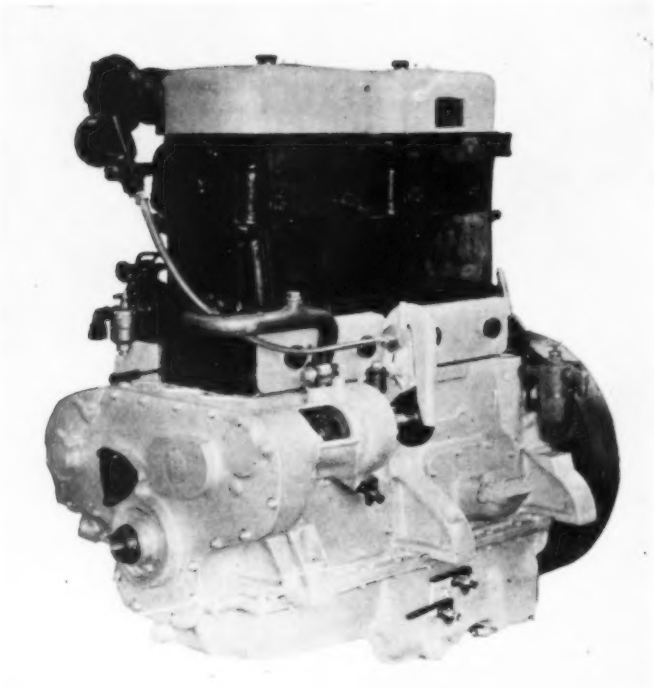
Economics.—Various speakers have touched the question of the price of fuel which of course is closely joined up with the anticipated economy from the introduction of the Diesel principle.

He entirely agreed with the author on the many advantages which accrue from high-flash fuels, and also appreciated the very frank opinion expressed by various speakers regarding the increase in price. This is to be expected in due course, as low grade fuel



Six-cylinder M.A.N. Light-weight High-speed Diesel Engine, developing 70/90 H.P. at 1,000/1,400 r.p.m.

FIG. 3.



Four-cylinder M.A.N. Light-weight High-speed Diesel Engine, developing 45/60 H.P. at 1,000/1,400 r.p.m.

FIG. 4.

when accepted for road transport, will automatically secure an enhanced economical value. Be this as it may, it does not in any way deter the importance of the light-weight high-speed Diesel engine and its necessary development. Apart from transport, there are many useful applications with resultant advantages and economies. The development of such a type of Diesel engine will enlarge its field of application in many directions and with it increase its value as an important economical factor in trade and industry.

Major Goddard wrote in reply :—

The Mercedes-Benz engine was the first and pioneer Diesel to be applied to road transport and has held top place ever since and was therefore, the one most likely to be of interest. Furthermore, the time did not permit of all the various Diesel engine designs being dealt with, although mention was made of others. Mr. Chaloner has got confused over "direct injection" and air compressors. The categories are "direct injection" and "pre-combustion chamber engine"—the air compressor does not come into this.

Mr. Chaloner need not doubt the figures given as these are from German Official and Technical Data.

The M.A.N. may be a very excellent engine, but the point is that it has not been thoroughly proved out over two years of hard road work in this country.

The author would very much doubt that the flexibility of the M.A.N. is as good as that of the Mercedes, but again, as it has not made its appearance here, this point remains to be proved. If Mr. Chaloner had had the experience which the author has actually had, i.e., nearly two years with the engine on the road, he might perhaps be a little less critical. We are out for economy and reliability on the road, and with the Mercedes, this has been obtained.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

RUMANIAN BRANCH.

After the Third Annual General Meeting of the Rumanian Branch of the Institution of Petroleum Technologists, on October 25th, 1929, when the Chair was taken by Mr. J. L. Chaillet, the following paper was read :—

The Development of the Wire Rope.

By Percy R. Clark (Associate Member).

Historical.—References are found to the manufacture and use of wire dating back to about 3000 B.C., but the wire rope as known to-day—*i.e.*, the helicoid—first appeared between the years 1832 and 1837, the first wire rope making machine being patented in 1840 by Newall. The first helicoidal ropes were made with 4, 6 or 8 strands of 4 wires each.

In 1879 a patent was taken out by John Lang for a rope in which all the strands and wires were twisted in the same direction, and this type of rope has since been known as Lang's Lay. The lock-coil rope (Figs. 1, 2 and 3) was patented by E. C. Batchelor in 1884, and the flat rope (Fig. 4) by H. R. I. Webster in 1886. The flattened strand rope (Figs. 5 and 6) was patented by Latch and Batchelor in 1888, and the idea of filling the interstitial spaces with fine wires was covered by J. B. Stone in 1890. In 1909, Newall and Skelton patented a non-twist rope of elliptical strands (Figs. 7 and 8), and in 1910 a rope with intermixed elliptical and triangular strands (Fig. 9) was patented by Leschen. E. C. Batchelor, in 1913, patented a lock-coil rope (Fig. 10) surrounded by a flattened strand, and in 1921 Roeblings covered a rope in which the core was enclosed in a metal band.

Point Contact versus Line Contact.—The length of the lay of the rope being the distance along the strand taken by the wire to make a complete circle, it is evident that there is a ratio between the

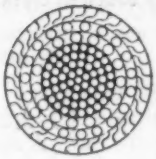


FIG. 1.

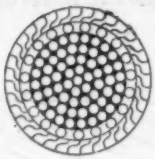


FIG. 2.

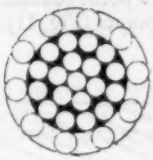


FIG. 3.

FIG. 4.

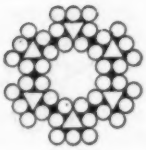


FIG. 5.

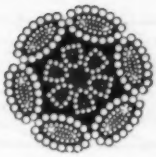


FIG. 6.

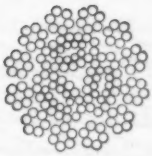


FIG. 7.

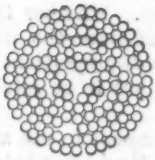


FIG. 8.

FIG. 9.

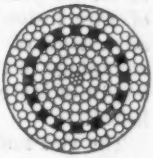


FIG. 10.

diameter of the spiral and the length of the lay. This is the principle of point contact in which the two layers of wire only touch at certain points (Fig. 11).

FIG. 11.

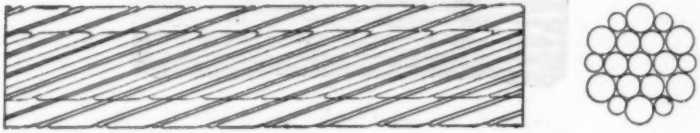


FIG. 12.

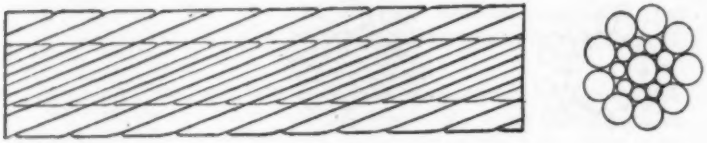


FIG. 13.

With line contact, the ratio of the lays is ignored and the outer and inner wires are in contact along their whole length, the effect of lateral pressure being thus distributed over the whole length of wire instead of at the points of contact only. Whether the advantage of resistance to lateral pressure overcomes the disadvantage of reduced tensile strength due to the disproportionate length of lay of the two layers of wire is a point yet to be established.

The two main classes of line contact rope at present in use are the Warrington (Fig. 12), and the Seale (Fig. 13), the former being largely used in the U.S.A. for drilling and bailing lines, and the latter for forestry haulage purposes.

It is possible that the application of the line contact principle to the filler type of rope, in which the interstices between the ordinary wires are filled with fine wires, will give a very solid strand.

Preforming Ropes.—An important modern development in wire rope manufacture has been the so-called preforming. In this system the wire strands are rolled instead of being drawn before entering the die—*i.e.*, they are given the necessary spiral form, by passing through suitably placed rollers, and then simply placed in their correct position in the die of the machine. The deleterious outer stresses are eliminated, the wires and strands lie dead, splicing is made easier, broken wires do not protrude, and there is less liability to kink.

Wire Ropes in the Rumanian Petroleum Industry.—The most marked factor in the petroleum industry recently has been the increased depths to which wells have been sunk. This has brought about serious changes in the requirements exacted from the wire rope.

First, the enormously increased tensile strain has caused severe lateral stresses on the lower layers of the rope adjacent to the drum, giving rise to crushing, or mashing, of the rope.

Secondly, producers have been using, for wells of depths as great as 1800 metres, drilling ropes of a breaking strain which was specified for wells of, say, 1000 metres. This has meant at times that the rope has been over strained.

It is not difficult to calculate the static stress on the rope. For instance, in a well 1800 metres deep being drilled with 6-inch piping, taking the weight of the drill-stem at 47·3 kgs. to the metre we have, together with tools, travelling blocks, etc., a load somewhere between 90 and 100 tons. Reckoning ten falls of rope, which is probably the maximum used, we have a total static load on the rope of 9 to 10 tons. Now the factor of safety is generally calculated at a minimum ratio of 6:1. That is to say that if the total static stress is 10 tons, the rope should have a breaking strain of 60 tons. This would mean, say, a wire rope of about 32 mm. in diameter and about 175/190 kg. per sq. mm. breaking strain. Now the so-called factor of safety is, in reality, a misnomer. It is calculated on the static stress only, without any regard to dynamic stresses, which dynamometer tests have sometimes shown to be momentarily as much as the static stresses.

As to the question of lateral stress. If the rope were simply a solid bar of metal, lateral stress would play a very small *rôle*, but a rope is necessarily a delicate and complicated piece of mechanism made up of a number of strands, each made up of a number of

wires, and, so that the rope may have a maximum of pliability, it is given generally a core of vegetable fibre. The point is, then, that to better resist lateral pressure one must solidify, as much as one dare, both strands and core.

The bailing rope, in Rumania, owing to the peculiar conditions of wire rope supply from abroad, which obtained until recently, has suffered from over-standardization. Practically the one diameter that was being used was the 18 mm., and this was used in the 150-metre well at Bustenari and the 1200-metre well at Moreni. Standardization and simplification are, within limits, the keynote of economy, but standardization such as this is standardization run amuck.

In 1927 the 9 mm. rope was introduced for bailing shallow wells, and in one report which the author had received the economy in electric power obtained by using a rope of this diameter was shown to exceed the total cost of the rope ; in other words, the expenditure on bailing ropes became less than nil. Undoubtedly, standardization in wire ropes, within certain limits is very desirable. Roughly something of the following nature would be a suitable scale :—

For wells up to	250	metres	..	..	..	9 mm.	diameter	rope.			
,, ,,	500	,,	..	..	..	11 mm.	or	12mm.			
,, ,,	705	,,	..	..	..	14 mm.	diameter	rope.			
,, ,,	1000	,,	..	..	..	16 mm.	,,	,,			
,, ,,	1500	,,	..	..	..	18 mm.	,,	,,			
,, ,,	2000	,,	..	..	..	20 mm.	,,	,,			

Pumping has come to the forefront in Rumania recently, but so far little attention has been directed to the possibility of applying the wire rope to this branch of production. Probably the reason for this is that the pump manufacturer is invariably a manufacturer of rods, but never of wire rope, and naturally the more timid producer may be led by his pump suppliers never to use the wire rope. Furthermore, the first wire ropes applied to this work were of the bailing or drilling type—lines which are too flexible and have too much stretch. Some six or seven years ago, however, non-rotating lines with very little stretch in them were introduced for this work. Since then the use of the wire rope for pumping has increased enormously. The author referred to an article from the pen of Mr. Wallace Davies, in the *Oil Weekly* of May 31st, 1929, to the effect that with the one company in Burma production is profitably carried out from wells of smaller productivity than anywhere else in the world. Fig. 14 is a rough scheme of their method of working as presented by Mr. Wallace Davies :—

The wells are grouped together into one power unit with which they are connected by jerker-rod lines, and a number of wells

have wire lines in place of rods. Here we have evidence that what appears to be the cheapest production in the world is done by pumps, some of which are worked with wire ropes. The author pointed out that some of the said ropes were supplied by a certain

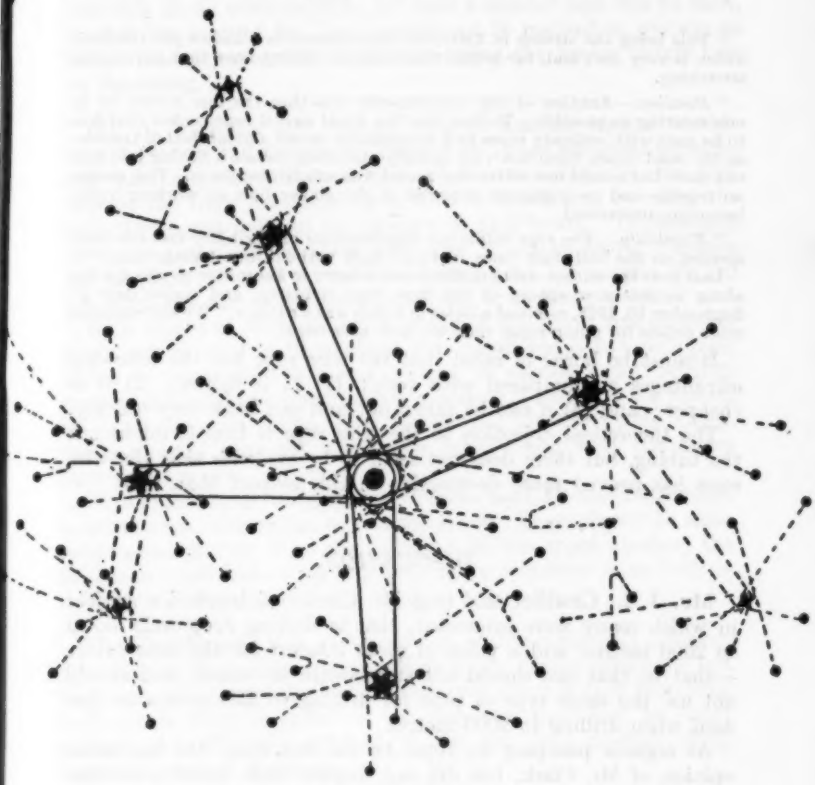


FIG. 14.

manufacturer known to the author. Under date of October 16th, 1924, the said manufacturer received a letter, of which the following is an extract :—

"*Stretch*.—One of our requirements was that there should be as little stretch in the rope as possible. The initial stretch in the line lasted a fortnight after which no further stretch has been evident.

"The following are the details :—

On 26/5/24 stretch taken up on line was				..	..	..	5	feet
„ 27/5/24	„	„	„	..	..	..	4	„
„ 28/5/24	„	„	„	..	..	..	2	„
„ 28/5/24 and 6/6/24	„	„		..	..	..	3	„
			Total	..	..	..	14	„

"This being the stretch in 2800 feet only represents 6 inches per 100 feet, which is very low, and, far better than the old drilling lines that never stop stretching.

"*Rotation.*—Another of our requirements was that the line should be as non-rotating as possible. To test this the usual swivel rope socket that has to be used with ordinary ropes and incidentally causes a great deal of trouble, as the sand wears them out very quickly and often causes a fishing job, was not used, but a solid non-swivelling socket was substituted for it. This causes no trouble and no instances occurred of the sinker bars or working valve becoming unscrewed.

"*Flexibility.*—The rope fulfils our requirements of flexibility and has been spooled on the bull shaft once or twice daily without any damage done."

Last year the author wrote to the manufacturer to know how he was getting along in this new sphere of the wire rope industry, and under date of September 10, 1928, received a letter in which was written : "We are receiving more orders for pump ropes than we have ever done."

It must be borne in mind that the wire rope has the following advantages as compared with rods : (1) It is lighter ; (2) it is cheaper ; and (3) it can be taken out and put back very quickly.

The theoretical objection to the wire rope is that it might cut the tubing, but there does not seem to be evidence that the wire rope has proved more destructive in this respect than rods.

DISCUSSION.

Mr. J. L. Chaillet said that Mr. Clark had touched a subject in which many were interested, that is drilling deep wells down to 2000 metres, and a point of great interest for the near future —that is, that one should not standardize too much, and should not use the same type of rope for drilling to 500 metres as that used when drilling to 2000 metres.

As regards pumping by rope, he did not share the optimistic opinion of Mr. Clark, but did not dispute that, under particular field conditions as mentioned regarding Burma, pumping might be definitely more cheaply done by rope. He considered there would be trouble in other ways—*e.g.*, when pulling the pump to effect repairs, such as to valves, when probably one would not get the valve back. One can of course pull much more quickly with a rope ; but he could not see as yet for the Rumanian fields the advantage of wire ropes for pumping over rods. What happens in certain fields, or certain parts of a field, cannot very well be

applied in a general way, and each producer has to consider whether the use of the rope in his particular part of the field is worth while.

The remark of Mr. Clark on bailing with standardized ropes impressed him, but he desired to comment upon the loads when drilling to 1800 metres with 6-inch drill-pipe. He did not expect that this would often happen, but that a smaller pipe will be used, so that the fears of Mr. Clark would not be realised so quickly as far as that is concerned when considering the heavy weight put on the string.

Mr. J. W. Elder said that he believed that the biggest trouble experienced in the Panhandle District of Texas has been paraffin, and quite a number of producers there were using the wire rope because the wells paraffined up in 9 to 10 hours, and by using the rope they could pull out the plunger in 1½/2 hours. In Rumania there are two districts where wire rope would be useful, Ceptura and Chiciura ; but where wells are running for 5/6 months, he did not think the wire would prove economic or as cheap as rods.

With regard to deep drilling with 6-inch drill-pipe, this diameter might not be used in Rumania at that depth but 5-inch drill-pipe, which is practically the same weight, is carried down to 1520 metres, and it is consequently only a matter of adding a few metres to it. As regards bailing lines, he did not agree with Mr. Clark, and suggested that the small wire rope would wear out faster than a larger one.

With regard to the shipping out of these lines, he found that there is not enough information put on the spool. There should be some information put on it so that, along with the spool number, the field man could trace it back a little closer and have more definite information regarding it.

Mr. Shaefer said that, in his opinion, air lift is the only solution, especially in view of the developments in the States during the last two years, and eventually it will be the only thing in deep producing wells where there is stress on the rods and wire such as exists to-day. Air lift also appears to be the only possible thing from the point of cheapness.

Mr. P. R. Clark, in reply, said that as regards pumping with wire ropes, what has happened in Burma was at least thought-provoking.

A vote of thanks was accorded Mr. Clark for his interesting paper.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

TRINIDAD BRANCH.

SECOND ANNUAL GENERAL MEETING.

THE Second Annual General Meeting of the Trinidad Branch of the Institution of Petroleum Technologists was held at the Club House, Apex (Trinidad) Oilfields, Ltd., Fyzabad, on Wednesday, February 26th, 1930. The Annual Report, together with the Accounts, for the year ending December 31st, 1929, were presented and passed.

There were three nominations to fill vacancies on the Committee caused by the retirement of Mr. W. J. C. Cooke (eligible for re-election) and Mr. C. A. P. Southwell and Comdr. H. V. Lavington, who have left the Colony, viz., Messrs. W. J. C. Cooke, H. W. Reid and A. G. V. Berry. These three gentlemen were, therefore, elected without ballot as Members of the Committee. Mr. A. G. V. Berry, while allowing himself to be elected to the Committee, intimated that pressure of work would necessitate his resigning as soon as another Member could be co-opted to assume the duties.

Later in the day a Committee Meeting was held at Fyzabad, when Mr. A. Frank Dabell was elected Chairman and Mr. H. W. Reid, Hon. Secretary and Treasurer.

Mr. C. A. Palmer-Chizzola was thanked for his services as Hon. Secretary during the period from the date of departure of Comdr. Lavington to the date of the Annual General Meeting, and was asked to continue to assist the Hon. Secretary.

The Committee of the Trinidad Branch now consists of the following Members: A. Frank Dabell (Chairman), A. G. V. Berry, W. J. C. Cooke, J. S. Parker, H. W. Reid (Hon. Secretary and Treasurer), A. J. Ruthven-Murray and G. H. Scott.

TRINIDAD BRANCH.

ANNUAL REPORT, 1929.

During the year seven Ordinary Meetings have been held, at which the following papers have been read:—

Ninth Ordinary Meeting, January 30th: "Notes on a New Mud Volcano in the Sea Off the South Coast of Trinidad," by W. G. Weeks, A.R.S.M., A.R.C.S., F.G.S., F.R.G.S.

Tenth Ordinary Meeting, February 27th: "Some Notes on Cretaceous Occurrences at Lizard Springs," by W. P. Jarvis, and "Some Notes on a Portion of the Lizard Springs Anticline," by R. H. Skelton.

Eleventh Ordinary Meeting, March 20th: "Corrosion in the Oil Industry," by Christopher Dalley, M.I.E.E.

Twelfth Ordinary Meeting, April 24th: "Accidents in Trinidad Oilfields," by C. A. P. Southwell, F.G.S.

Thirteenth Ordinary Meeting, October 30th: "Measurement and Sampling of Mineral Oil," by J. S. Parker, M.A., B.Sc.

Fourteenth Ordinary Meeting, November 27th: "Casing Shoes are Unnecessary in Rotary Drilled Wells," by A. Frank Dabell, M.I.Min.E.; "The Capacity of the Barrel," by O. F. Nothnagel; and "Mud Flow," by C. C. Wilson, A.R.S.M.

Fifteenth Ordinary Meeting, December 18th: "Chemical Control in the Fields," by B. A. Craig, M.Am.Chem.Soc.

The average attendance at these meetings was 29 members and friends, who keenly discussed the details of the matters presented. At the December 31st, 1929, the membership of the Trinidad Branch numbered 25.

The Committee take this opportunity of putting on record their appreciation of the zealous service rendered by Comdr. H. V. Lavington, now transferred to Ecuador, who from the foundation of the Branch carried out the duties of Hon. Secretary and Treasurer.

The accounts for the year ended December 31st, 1929, duly audited by Messrs. F. Middleton and D. M. Walsh, are laid on the table and show the satisfactory condition of the finances of the Branch.

A. Frank Dabell (Chairman).

C. A. Palmer-Chizzola
(Acting Hon. Secretary).

THE INSTITUTION OF PETROLEUM

CASH ACCOUNT FOR THE YEAR

RECEIPTS.

		$
	Balance at Dec. 31st, 1928, as per audited account	58.80
	Received on account of registrations to Local Branch since Dec. 31st, 1928	7.00
Jan. 17.	To London Office grant for quarter ended March 31st, 1929 ..	28.52
April 3.	,, London Office grant for quarter ended June 30th, 1929..	28.54
July 17.	,, London Office grant for quarter ended Sept. 30th, 1929 ..	28.54
Oct. 31.	,, London Office grant for quarter ended Dec. 31st, 1929 ..	28.54
		$179.94

ACCOUNT OF INCOME AND EXPENDITURE

			$
To Stationery			3.06
,, Postages			6.11
,, Stenographer, 5 papers	$49.00		
,, ,, Outstanding	30.00		
			79.00
,, Balance, being excess of Income over Expenditure			32.97
			$121.14

BALANCE SHEET AS AT

			$
Profit and Loss Account :—			
Receipts for year ended Dec. 31st, 1928	$155.38		
Expenditure for year ended Dec. 31st, 1928	96.58		
Excess of Income over Expenditure for year ended Dec. 31st, 1928 ..			58.80
Receipts for year ended Dec. 31st, 1929	$121.14		
Expenditure for year ended Dec. 31st, 1929	88.17		
Excess of Income over Expenditure for year ended Dec. 31st, 1929 ..			32.97
Creditor, Stenographer—2 papers, 14 and 15			30.00
			$121.77

Examined, Audited and found correct,

F. MIDDLETON
D. M. WALSH } *Auditors.*

February 25th, 1930.

TECHNOLOGISTS (TRINIDAD BRANCH).

ENDED DECEMBER 31ST, 1929.

PAYMENTS.

			$
Feb. 27.	By	Payment to Stenographer	10.00
Mar. 19.	„	Payment to Stenographer	10.00
April 8.	„	Yuille's Printerie	3.06
May 17.	„	Payment to Stenographer	14.00
June 30.	„	Stamps to date	4.11
Dec. 10.	„	Payment to Stenographer, Paper 13	15.00
Dec. 14.	„	Stamps to date	2.00
Dec. 31.	„	Balance at Bank	121.77
			$179.94

FOR THE YEAR ENDED DECEMBER 31ST, 1929.

	$
By Monthly Grants from Institution, London	114.14
Received on account of Members Registration, 7 Members @ $1.00 ..	7.00
	$121.14

DECEMBER 31ST, 1929.

	$
Cash at Bank, Dec. 31st, 1929	121.77
	$121.77

INSTITUTION OF PETROLEUM TECHNOLOGISTS (TRINIDAD BRANCH)

A. FRANK DABELL (*Chairman*).
C. A. PALMER-CHIZZOLA (*Acting Hon. Secretary*).

On the Variation With Temperature of the Specific Heat of Typical Crude Oils and Their Residues When Topped to 100° C.*

By H. R. LANG, Ph.D., F.Inst.P., Research Fellow I.P.T., and R. JESSEL, A.R.C.S., D.I.C., B.Sc., Demonstrator, Imperial College of Science, with an introduction by H. R. LANG.

Summary.—The paper describes experiments performed at the Imperial College of Science and Technology on the specific heats of typical crude oils and their residues when topped to 100° C. The measurements were made by the Continuous Flow Electric Method of calorimetry, which yields results accurate to at least 0·2 per cent., up to 100° C., and over short ranges of temperature. The specific heat-temperature curves which have been plotted show the effect of wax and high melting point constituents in the oil, and a rapid rise of specific heat near the initial boiling point due to the presence of vapour in solution. An approximate relation has been found connecting the specific heat with the specific gravity, and this has been compared with the equations of other observers. Tables of the total heat of the oils have been calculated for every degree centigrade over the range of the experiments. The method of performing the experiments and the apparatus used is briefly described.

1. *Introduction by H. R. Lang.*—Towards the end of 1926, the attention of the writer was directed by Mr. A. A. Ashworth, to the great lack of reliable data of the thermal properties of mineral oils and other products. In order to design efficient stills and condensers it is necessary to know these properties, and in view of the rapid development of the oil industry the matter has now become one of great importance. At the time, measurements were being made on the specific heat of aniline by the continuous flow electric method, and the apparatus had only to be slightly modified to adapt it for work with oil. At the commencement of the session, 1927-1928, the matter was further discussed with Mr. Wolf of the Oil Technology Department of the Imperial College, and he undertook the necessary distillations and the analytical part of the work, while the writer undertook the physical measurements in his laboratory in the Physics Department of the Imperial College.

* Paper received March 1, 1930.

The chief difficulty is the vastly complicated nature of the crude oil. Once distillation has commenced, the temperature of the vapour continues to rise steadily, so that the terms latent heat, boiling-point, etc., have no real meaning. It is only possible therefore to determine the change of total heat at the various stages of the distillation.

The problem is then threefold :—

1. To measure the total heat of the crude and the residue in the still, at each stage of the distillation and at various temperatures.

2. To measure the total heat of the vapour of the various short boiling-range fractions, at atmospheric and reduced pressures, and at various temperatures.

3. To measure the total heat of the various fractions at different temperatures.

It was decided to commence the work by studying a series of typical crude oils and to measure their specific heats over short ranges of temperature, using the apparatus built for the aniline work. From these values the total heat, measured from some arbitrary zero, could be found at different temperatures. Those fractions that distilled off below 100°C. were then removed, and the remaining "topped oil" re-investigated over the whole range of temperature. By March, 1928, the existing apparatus had been suitably modified, and with the assistance of Mr. W. Goldsmith a series of observations commenced. These experiments were most successful, and a further series were undertaken and completed before the end of July. At the commencement of the session, 1928-1929 the work was continued with the help of Mr. R. Jessel, who after a short while, had gained such a knowledge of the complicated apparatus that it was possible to leave this part of the work to him, with but occasional supervision.

2. *General Outline of the Method.*—The principle of the method is to allow a stream of the oil to flow through a fine bore glass tube, through which passes an electrically heated manganin strip, and to measure the rise in temperature resulting from a given steady supply of electrical energy. A very full discussion of the method has been given by Prof. Callendar and Dr. Barnes,*, in their classical papers on the measurement of the variation of the specific heat of water with temperature.

The subject has further been discussed and much of the present apparatus described in a paper by Lang.†

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* *Phil. Trans. A.*, 1902, **199**, 55, 149.
† *Proc. Roy. Soc. A.*, 1928, **118**, 138.

Reference to these papers will be indicated below by the name and the page. It will suffice here to state briefly the advantages of the method. These are :—

1. The specific heat can be found over short ranges of temperature and at any point of the scale.

2. The temperature rise can be measured directly with a differential pair of platinum thermometers, and the readings being steady can be measured to 0·002°C.

3. The method is independent of the water equivalent of the calorimeter.

4. There can be no evaporation from the liquid in the calorimeter.

5. The heat loss is extremely small, and of approximately the same value whatever the temperature. It is actually measured and eliminated in each case.

The elementary theory of the method is as follows ;

If E is the p.d. between the ends of the heater in volts,
C current in amperes,
Q the rate of flow of the liquid in grams per second,
s specific heat of the liquid,
J the mechanical equivalent of heat,
$d\theta$ rise in temperature in degrees Centigrade,
h rate of loss of heat, in watts, per degree rise in temperature,

then, when the conditions are steady, the energy equation per second is

$$EC = JsQd\theta + hd\theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

By changing the watts EC and the rate of flow Q in such a manner as to keep the rise $d\theta$ constant, two equations are obtained from which h can be accurately eliminated and s found. In practice it would be a long and tedious process to arrange for the value of $d\theta$ to be exactly the same, so that a value within 1 per cent. is obtained and the equations reduced as follows :

from equation (1) $Q_1X_1 = JsQ_1 + h$ where $X = EC/Qd\theta$

also $Q_2X_2 = JsQ_2 + h$

whence $s = (Q_1X_1 + Q_2X_2)/J(Q_1 - Q_2)$

It is to be noted that h is assumed to be independent of both Q and $d\theta$; the necessary conditions for this have been carefully investigated and in these experiments great trouble was taken to ensure that these conditions were fulfilled.

The electrical and other measurements, as well as the thermometric ones, were made precisely as described previously (Lang, p. 139). The various instruments were all recalibrated and found not to have changed. The standard cells and resistance had been sent to the N.P.L., so that the results are expressed in terms of the international standards, with which these were compared. A heavy manganin wire standard resistance specially designed for

large currents was used, instead of the platinum silver one used in the aniline experiments.

3. *The calorimeters.*—Six different calorimeters were used for this work, but of these only four were used in the actual measurements. They were all similar to Calorimeter A (Lang p. 143) and were made by Messrs. The National Glass Industry of London, who also silvered and exhausted the vacuum jackets. Except that the diameters of the flow tubes were different, the dimensions were exactly the same as Calorimeter A (loc. cit.). The calorimeters will be referred to as Nos. 1 to 6. The vacuum jacket of No. 2, which was of lead glass, developed a crack before it could be used; all the other calorimeters were of soda glass. No. 4 had a very fine bore flow tube, but it was impossible to get sufficiently fast flows and this had to be replaced. The diameters of the other flow tubes were as follows: No. 1, 2mm.; No. 3, 3mm.; No. 5, 2½mm.; and No. 6, 3mm. The latter calorimeter has not yet been used, and is kept as a stand-by in case of accident to the one in use.

In all the later ones the rubber packing round the copper cups (Lang, p. 144) was replaced with silk cord, which has proved most satisfactory at high temperatures where rubber is likely to be attacked by the oil.

4. *Flow circuits.*—The water flow circuits for the jacketing, and the arrangements for maintaining it at a steady temperature were as before (Lang, p. 145). The liquid flow circuit was also the same with the addition that one side of the special two way tap *K* (Fig. 1) was connected to the glass reservoir *S*, and from here the oil was pumped by a small rotary pump *P* to the storage tank *C* on the floor above. This tank had a large surface area so that the rate of fall of head was only of the order of one part in 3,000 during an experiment on the fastest flows. This was found to be sufficiently constant. Evaporation from the surface was reduced to a minimum by having an air tight lid with only a capillary air port, which was kept closed except when the oil was flowing. A wire gauze filter was placed over the outlet tap *F* and a Zenith petrol filter *Z* was introduced just before the capillary throttles *G*, to prevent any solid particles from entering the calorimeter.

5. *Oils used.*—The specimens of oil were kindly supplied by Mr. A. Wolf, who was also good enough to have them topped in his laboratory. The details of each will be found in the summarised observations. The apparatus was thoroughly cleaned before the introduction of each oil, by running through first petrol and then benzene, until it came out perfectly clear. Air was then left passing through for some hours, and finally the whole apparatus was exhausted.

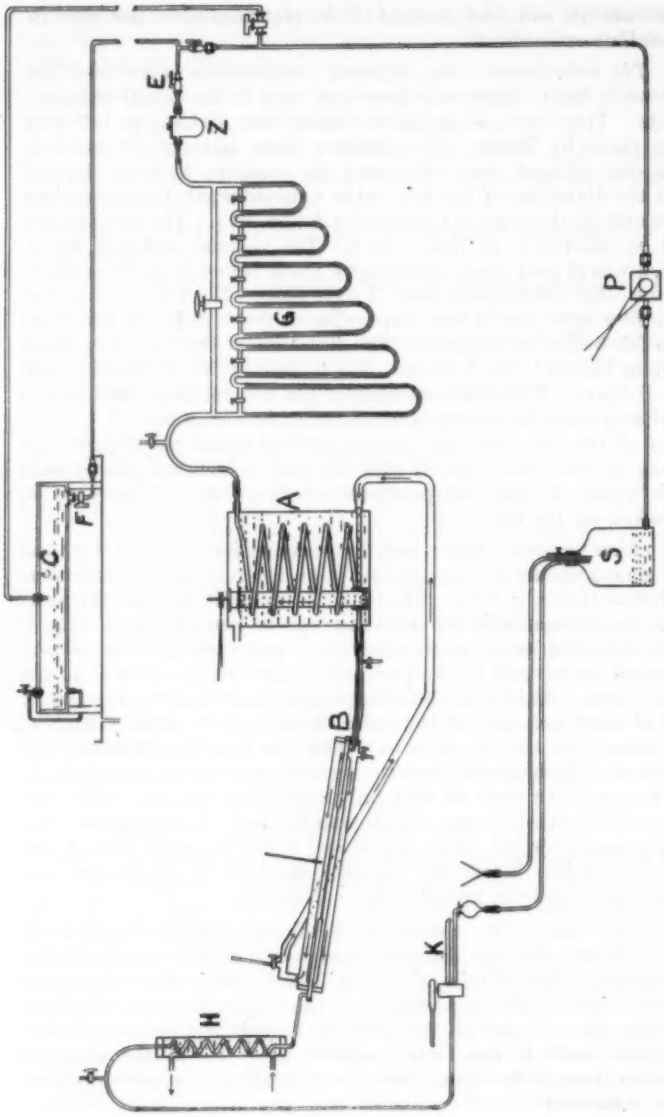


FIG. 1.
FLOW CIRCUITS.

6. *Method of making an experiment.*—The method of conducting an experiment was as previously described (Lang p. 147). The temperature control of the thermostat however was much more satisfactory, as all the heaters were electrical, which eliminated errors due to the fluctuations in gas pressure. It was found possible to obtain quite steady conditions at any desired temperature between 0°C. and 100°C.

Every experiment was repeated and the agreement was remarkable, being usually about 1 part in 2,000. On some occasions three or four rates of flow were taken in order to test whether the heat loss was independent of the flow as required by the theory; the results of these tests are given below.

7. *The "X" Tests and Heat Loss.*—It is essential for the success of the experiments that the flow through the fine bore tube of the calorimeter should be turbulent. In the case of some of the oils at the lower temperatures the viscosity became so high that some doubt was entertained as to whether this was the case. Fortunately

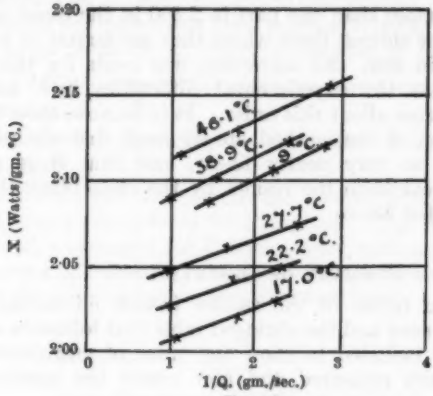


FIG. 2.

SOME TYPICAL X CURVES.

it was possible to test this point experimentally by performing an "X test." In order to do this, three or four rates of flow were used and the values of X plotted against 1/Q.

Equation (1) may be written:

$$X = EC/Qd\theta = Js + h/Q$$

If there is turbulent flow, h is independent of Q and the graph should be a straight line. These tests have proved most satisfactory, and some typical curves are given in Fig. 2. It will be observed

that the points lie on the straight line to less than 1 part in 1,000, which is the experimental error. In a few special cases the X-test showed that under those particular conditions the method was not satisfactory. These are discussed later.

Although curves were plotted to show the relation between h and the mean temperature of the experiment, it serves no purpose to reproduce them here, as the value of h is actually measured and eliminated in each case. It may be mentioned, however, that h was found to be nearly proportional to the mean temperature of the experiment and to depend to some extent on the previous history of the calorimeter, the reason for the latter is, no doubt, the release of occluded gas from the silvered walls of the vacuum jacket.

In the published papers on the application of the method (Callendar and Barnes, loc cit.) a full discussion of possible sources of error, and the corrections applicable will be found. It is not proposed therefore to deal with them here in detail. A calculation of these corrections based on the reasoning given, showed them to amount to not more than one part in 2,500 in the usual case, and in the case of the slowest flows where they are largest to not more than one part in 400. No correction was made for this on the slowest flows, as the experimental difficulties here make the experimental errors about this order. It is because these terms in the full equation of the method are so small that the plot of X against 1/Q is so very nearly linear, and that it is perfectly satisfactory to calculate the results by the elementary theory on the lines indicated above.

Summary of Observations.

The complete tables of the results (which fill several books) have been preserved and the abridged table that follows is a typical example; it is included to show the order of magnitude of the various quantities measured and how nearly the results can be repeated.

Column I.—Column I gives the date of the experiment for purposes of reference to the original books of observations.

Column II.—Column II gives the inflow temperature reduced to the gas scale, and is the mean of the values at the beginning and end of a " run," and which usually differed by less than 0·005° C.

Column III.—Column III contains the mean temperature rise, reduced to the gas scale, and is the mean of the readings taken every half-minute during a five-minute " run," or every minute during a 10-minute " run." In the case of the more viscous oils,

when the rate of flow was so much slower, it was found better to take 10-minute "runs," but, when a sufficiently large rate of flow could be obtained, a "run" of five minutes gave ample accuracy.

Column IV.—Column IV gives the watts supplied to the manganin heating strip, and was calculated from a series of readings, taken at regular intervals, of the potential difference across the standard resistance coil, and across the heater itself.

Column V.—Column V is the rate of flow in grammes per second, corrected for buoyancy.

Column VI.—The calculated values of $X=EC/Qd\theta$ are given in Column VI, and the remarkable agreement for successive "runs" on the same rate of flow shows how precisely the results could be reproduced. In calculating the results, the mean value of X has been used in each case.

Column VII.—Column VII gives the value of the specific heat in gramme calories per gramme degree Centigrade. As the value of the mechanical equivalent has been taken as 4·180 joules per calorie, this is in terms of the 20° C. calorie (Callendar, p. 132).

Column VIII.—Column VIII gives the mean temperature of the experiment.

Column IX.—Column IX gives the value of the heat loss in watts per degree (h).

Column X.—In the last column the specific gravity reduced to 60° F. and in terms of water at 60° F. is given. This was determined each day with a standard I.P.T. hydrometer, with an open scale, in order to keep a check on the evaporation of the lighter constituents of some of the oils; this is further discussed below.

TABLE I.

Crude Pennsylvanian Oil Topped to 100° C.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Jan. 25 ..	24·95	9·089	14·691	0·8069	2·003				
	24·96	9·087	14·684	0·8063	2·004				
						0·4724	29·5	0·0234	0·8532
	24·98	8·910	4·913	0·2673	2·062				
	24·98	8·894	4·913	0·2677	2·063				
Jan. 28 ..	25·81	8·141	13·041	0·7965	2·011				
	25·82	8·171	13·037	0·7931	2·012				
						0·4746	29·9	0·0218	0·8533
	25·84	8·076	5·307	0·3201	2·053				
	25·85	8·046	5·307	0·3216	2·051				

TABLE I.—*continued.*

Crude Pennsylvanian Oil Topped to 100° C.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Jan. 30 ..	45·00	8·465	16·227	0·9224	2·078				
	45·01	8·445	16·215	0·9232	2·080				
						0·4903	49·23	0·0271	0·8532
	45·03	8·405	6·077	0·3395	2·130				
	45·07	8·411	8·694	0·4912	2·104				
	45·07	8·417	8·960	0·4907	2·104	0·4902	49·28		
Jan. 31 ..	55·78	8·084	16·721	0·9749	2·122				
	55·78	8·067	16·722	0·9757	2·124				
						0·5012	59·8	0·0259	0·8536
	55·78	8·071	6·263	0·3579	2·168				
	55·79	8·063	6·260	0·3581	2·168				
	55·83	8·107	9·072	0·5231	2·139	0·5000	59·9		
Feb. 7 ..	68·13	7·569	17·565	1·0700	2·169				
	68·13	7·539	17·550	1·0727	2·170				
						0·5118	71·9	0·0328	0·8534
	68·14	7·533	6·528	0·3898	2·223				
	68·16	7·517	6·524	0·3906	2·222				
	68·15	7·656	9·507	0·5650	2·198	0·5119	72·0		
Feb. 8 ..	15·28	8·281	10·827	0·6587	1·985				
	15·27	8·293	10·818	0·6573	1·985				
						0·4661	19·5	0·0241	0·8537
	15·29	8·360	5·081	0·2994	2·030				
	15·30	8·372	5·079	0·2992	2·027				
Feb. 19 ..	78·77	8·306	16·895	0·9161	2·220				
	78·78	8·316	16·892	0·9146	2·221				
						0·5239	82·9	0·0283	0·8534
	78·66	8·242	7·398	0·3968	2·262				
	78·66	8·226	7·396	0·3978	2·260				
	78·72	8·316	10·662	0·5728	2·238	0·5238	82·9		
	78·72	8·306	10·662	0·5731	2·240				
Feb. 22 ..	9·95	8·144	9·329	0·5774	1·984				
	9·97	8·201	9·325	0·5726	1·986				
						0·4679	14·04	0·0165	0·8539
	9·96	8·128	5·562	0·3413	2·005				
	9·96	8·134	5·560	0·3409	2·004				
	9·93	8·152	7·194	0·4423	1·995	0·4684	14·00		
Feb. 26 ..	6·98	8·261	7·322	0·4369	2·029				
	6·99	8·251	7·320	0·4375	2·028				
						0·4725	11·13	0·0233	0·8536
	7·02	8·234	4·769	0·2816	2·057				
	7·02	8·226	4·769	0·2817	2·058				
	7·00	8·210	5·766	0·3435	2·045				
	7·00	8·234	5·785	0·3435	2·045	0·4730	11·11		
	6·99	8·295	5·438	0·3201	2·048	0·4724	11·14		
	6·98	8·283	5·436	0·3206	2·047				

TABLE I.—*continued.*

Crude Pennsylvanian Oil Topped to 100° C.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
Mar. 1 ..	13·48	6·263	7·032	0·5670	1·980				
	13·48	6·251	7·029	0·5673	1·978				
						0·4658	16·62	0·0175	0·8546
	13·52	6·200	4·014	0·3233	2·002				
	13·52	6·202	4·013	0·3231	2·003				
	13·53	6·249	4·981	0·4006	1·990				
	13·44	6·193	4·979	0·4047	1·991	0·4661	16·60		
Mar. 4 ..	89·92	6·198	12·032	0·8582	2·262				
	89·93	6·204	12·018	0·8571	2·260				
						0·5316	92·96	0·0336	0·8544
	89·78	6·203	4·435	0·3066	2·332				
	89·78	6·218	4·434	0·3061	2·330				
	89·96	6·286	7·687	0·5355	2·284	0·5309	93·12		
Mar. 6 ..	36·37	8·431	15·406	0·8960	2·039				
	36·38	8·427	15·392	0·8953	2·040				
						0·4817	40·55	0·0237	0·8547
	36·33	8·387	5·741	0·3281	2·086				
	36·33	8·367	5·738	0·3289	2·085				
	36·37	8·347	7·931	0·4597	2·067				
	36·37	8·323	7·925	0·4606	2·068	0·4823	40·54		
Mar. 7 ..	19·70	8·046	12·180	0·7601	1·991				
	19·71	8·022	12·175	0·7616	1·993				
						0·4705	23·68	0·0198	0·8546
	19·70	7·964	5·153	0·3193	2·026				
	19·73	8·020	5·218	0·3207	2·029				
	19·53	7·991	5·216	0·3223	2·025				
Mar. 8 ..	89·79	5·539	12·124	0·9731	2·251				
	89·79	5·550	12·120	0·9695	2·252				
						0·5309	92·36	0·0309	0·8551
	89·44	5·476	4·067	0·3208	2·315				
	89·44	5·466	4·066	0·3211	2·317				

9. *Summary of experimental results.*—The following tables (II.—VIII.) give a summary of the results obtained up to the present time. The specific heat of the crude oils was measured almost up to the temperature at which the lightest constituents commence to boil. The lower limit was set by the rapid increase in the viscosity of the oils below about 15° C., which prohibited the use of suitable rates of flow, with the available head. After topping to 100° C. it was possible to make experiments almost up to this temperature, and the lower limit again was set by the viscosity.

The more important experimental difficulties that were encountered in the various cases are also discussed here.

(*a*) *Pennsylvanian Crude Oil.*—A series of determinations was carried out in March, 1928. The storage tank on the upper floor consisted of three 10-gallon drums connected in parallel, in order to provide the large surface area necessary to maintain the head nearly constant. There was only one pipe connecting these to the apparatus, so that the oil could not be pumped up while it was flowing through the calorimeter. The calorimeter used was No. 1, and had a 2mm. bore flow tube.

The values obtained are given below and are plotted in Fig. 3, a smooth curve being drawn among the points.

TABLE II.

Pennsylvanian Crude Oil

Date. 1928.	Specific Heat, cals./grm. ° C.	Mean Temperature, ° C.	Specific Gravity, 60° F./60° F.
March 2	0·4682	14·0	0·8395
	0·4682	14·0	
„ 6	0·4688	21·7	0·8396
	0·4683	21·6	
„ 8	0·4715	29·5	0·8392
„ 9	0·4828	36·3	0·8395
„ 12	0·4692	21·3	0·8396
„ 14	0·4692	11·5	0·8395
„ 15	0·4789	34·4	0·8395
„ 16	0·4767	31·9	0·8398
	0·4777	31·9	
„ 19	0·4805	35·9	0·8397

(*b*) *Persian Crude Oil.*—For the work on this oil, calorimeter No. 3 was used, the remainder of the apparatus being precisely as before. Now this wide flow tube, while allowing a faster rate of flow with the same head, has some disadvantages. Principally the defect of the "X" curves from linearity is greater than with the narrower bore. This means that the additional term in the equation given by the simple theory (para. 7 above) which varies as $1/Q$ is a little greater, but is still outside the accuracy of the experiments. Further, such a wide bore flow tube has a larger surface area, and therefore a greater heat loss. It was noticed that the value of h was not nearly so consistent as with the narrower bore calorimeters and Barnes (p. 210) noticed the same thing in his work on water by this method. This is most likely due to the heating strip being slightly displaced and touching the sides of the tube in different places which it would more easily do in a wide tube than in a narrow one. It is however to be noted that the value of h is actually measured in each case, so that these slight defects do not affect the results.

In two of the experiments, at a mean temperature of about 30° C. it was found that for the highest rates of flow used (about 1.5 gms. per sec.) the points came well above the "X" curve, and here there is the least probability of stream-line flow. The explanation is that with such a fast rate of flow and with a rise in temper-

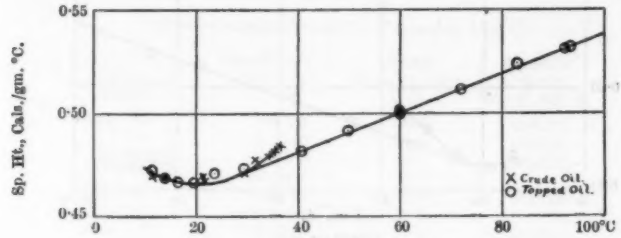


FIG. 3.

PENNSYLVANIAN OIL.

ature of 8° C. about 25 watts had to be dissipated by the heating strip. Now this will cause it to superheat to some extent, and at this temperature and with this light oil boiling may have occurred in the immediate vicinity of the strip. These values were not therefore used in calculating the results, and the experiments were repeated under more favourable conditions.

TABLE III.

Persian Crude Oil.

Date. 1928.	Specific Heat, cals./grm. ° C.	Mean Temperature, ° C.	Specific Gravity, 60° F./60° F.
June 29 ..	0·4786 ..	30·2 ..	0·8463
July 2 ..	0·4797 ..	30·5 ..	0·8465
	0·4801 ..	30·5 ..	
,, 4 ..	0·4687 ..	24·9 ..	0·8466
,, 9 ..	0·4657 ..	24·1 ..	0·8474
	0·4662 ..	24·1 ..	
,, 12 ..	0·4620 ..	15·5 ..	0·8482
,, 16 ..	0·4627 ..	19·5 ..	0·8487
,, 23 ..	0·4762 ..	30·7 ..	0·8503
,, 27 ..	0·4862 ..	35·8 ..	0·8508
	0·4854 ..	35·8 ..	

These results are plotted in Fig. 4.

(*c*) *Persian Crude Oil topped to* 100° *C.*—The crude oil used in series (*b*) was now topped to 100° C. and the specific gravity thereby was increased to 0·8690. Meanwhile a large portion of the apparatus had had to be dismantled during the vacation and was

rebuilt at the end of 1928. At first a very narrow bore calorimeter was tried, but this was unsatisfactory, and was replaced by No. 5 (2½mm. bore). This calorimeter has proved most satisfactory, and was used for all the subsequent experiments. The special

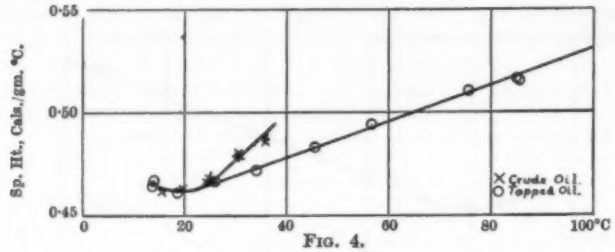


FIG. 4.

PERSIAN OIL

tank described above (para. 4) was made and also a separate pipe to pump up the oil was added, as shown in Fig. 1. By a suitable arrangement of taps, it was possible to pump the oil up the main pipe and into the tank through the tap *F*. (Fig. 1.) This was useful in filling the apparatus, and in keeping the filter and the pipes clear.

TABLE IV.

Persian Crude Oil Topped to 100° C.

Date. 1928.	Specific Heat, cals./grm. ° C.	Mean Temperature, ° C.	Specific Gravity, 60° F./60° F.
Nov. 20 ..	0·4674	.. 26·9	.. 0·8682
	0·4669	.. 26·9	..
	0·4671	.. 26·9	..
„ 30 ..	0·4675	.. 25·1	.. 0·8692
	0·4676	.. 25·1	..
	0·4673	.. 25·1	..
Dec. 4 ..	0·4652	.. 13·7	.. 0·8689
	0·4671	.. 13·8	..
„ 6 ..	0·4723	.. 34·0	.. 0·8684
	0·4724	.. 34·0	..
„ 7 ..	0·4831	.. 45·3	.. 0·8693
„ 11 ..	0·4619	.. 18·4	.. 0·8693
	0·4620	.. 18·9	..
„ 17 ..	0·4937	.. 56·7	.. 0·8690
„ 20 ..	0·4993	.. 64·2	.. 0·8693
„ 31 ..	0·4656	.. 15·7	.. 0·8695
1929.			
Jan. 1 ..	0·5104	.. 75·6	.. 0·8696
„ 2 ..	0·5154	.. 85·5	.. 0·8694
„ 7 ..	0·5164	.. 85·1	..
	0·5158	.. 85·0	..

These results are plotted in Fig. 4.

(*d*) *Pennsylvanian Crude Oil topped to* 100° *C.*—The apparatus was cleaned, and refilled with the sample of Pennsylvanian Crude Oil, which had been topped to 100° C.

TABLE V.

Pennsylvanian Crude Oil Topped to 100° *C.*

Date. 1929.	Specific Heat, cals./grm. ° C.	Mean Temperature, ° C.	Specific Gravity, 60° F./60° F.
Jan. 25	0·4724	29·5	0·8532
„ 28	0·4746	29·9	0·8533
„ 30	0·4903	49·2	0·8532
	0·4902	49·3	
„ 31	0·5012	59·8	0·8536
	0·5000	59·9	
Feb. 7	0·5118	71·9	0·8534
	0·5119	72·0	
„ 8	0·4661	19·5	0·8537
„ 19	0·5239	82·9	0·8534
	0·5238	82·9	
„ 22	0·4679	14·0	0·8539
	0·4684	14·0	
„ 26	0·4725	11·1	0·8536
	0·4730	11·1	
	0·4724	11·1	
Mar. 1	0·4658	16·6	0·8546
	0·4661	16·6	
„ 4	0·5316	93·0	0·8544
	0·5309	93·1	
„ 6	0·4817	40·6	0·8547
	0·4823	40·5	
„ 7	0·4705	23·7	0·8546
„ 8	0·5309	92·4	0·8551

These results are plotted in Fig. 3.

(*e*) *Californian Crude Oil.*—Before commencing the series of experiments on this oil, a glass to metal joint was made to replace the slip joint which connected the spiral in the tank A (Fig. 1) to the glass calorimeter. This joint had been the source of much trouble, but since the introduction of the new one no further difficulty had been experienced.

It was not possible to experiment below 30° C. with this oil, owing to its high viscosity. Great care had to be exercised to ensure that the flow was turbulent, and in cases when this was found not to be so the experiments were repeated under more favourable conditions. Two series of experiments were performed on this oil; the first over a range of 30° C. to 50° C. and, it subsequently being found that the oil did not commence to boil till well over 100° C., the oil was put back into the apparatus and after a lapse of three months values were obtained up to 100° C.

TABLE VI.

Californian Crude Oil.

Date. 1929.	Specific Heat, cals./grm. ° C.	Mean Temperature, ° C.	Specific Gravity, 60° F./60° F.
Mar. 26	0·4524	44·4	0·9315
„ 28	0·4492	39·9	0·9310
	0·4490	40·0	0·9310
April 3	0·4430	34·0	0·9303
„ 4	0·4448	34·8	0·9314
„ 5	0·4563	48·2	0·9313
„ 8	0·4400	31·0	0·9321
July 10	0·4630	56·1	0·9329
„ 11	0·4847	76·1	0·9333
„ 12	0·5008	96·1	0·9337
„ 15	0·4854	78·3	0·9339

These results are plotted in Fig. 5.

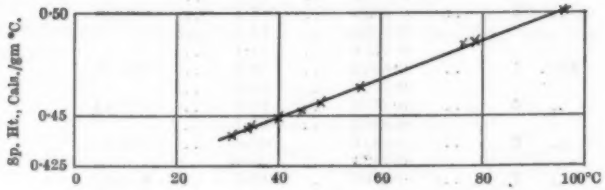


FIG. 5.

CALIFORNIAN CRUDE OIL.

With this heavy oil some difficulty was experienced in obtaining a uniform temperature throughout the volume used for measuring the specific gravity, and the results given may be less accurate than in other cases. On two occasions (April 3rd and 8th), although two different rates of flow were used, only the faster was found to be turbulent, so that a value of the specific heat was obtained by applying an interpolated value of the heat loss from the results of other experiments on this oil.

(*f*) *Mid-Continent Crude Oil.*—With this light oil it was possible to make experiments from 0° C. up to about 50° C., at which temperature the lighter fractions commence to boil.

TABLE VII.

Mid-Continent Crude Oil.

Date. 1929.	Specific Heat, cals./grm. ° C.	Mean Temperature, ° C.	Specific Gravity, 60° F./60° F.
April 16 ..	0·4762 ..	17·0 ..	0·8239
	0·4765 ..	17·0 ..	
„ 17 ..	0·4810 ..	22·2 ..	0·8246
	0·4812 ..	22·3 ..	
„ 18 ..	0·4847 ..	27·7 ..	0·8252
	0·4852 ..	27·7 ..	
„ 19 ..	0·4893 ..	34·0 ..	0·8261
	0·4941 ..	38·9 ..	0·8261
	0·4937 ..	38·9 ..	
„ 23 ..	0·4918 ..	9·0 ..	0·8274
	0·4920 ..	9·0 ..	
„ 24 ..	0·5121 ..	3·7 ..	0·8274
May 3 ..	0·4739 ..	14·4 ..	0·8290
„ 6 ..	0·4710 ..	11·3 ..	0·8296
„ 8 ..	0·5010 ..	46·1 ..	0·8299
	0·5004 ..	46·2 ..	
„ 9 ..	0·4726 ..	11·5 ..	0·8304
„ 10 ..	0·5151 ..	4·0 ..	0·8302
„ 13 ..	0·4973 ..	7·8 ..	0·8311

These results are plotted in Fig. 6.

(*g*) *Mid-Continent Crude Oil topped to* 100° *C.*—Another sample of the oil from the same barrel as the crude was topped to 100° C., and the following results obtained :—

TABLE VIII.

Mid-Continent Crude Oil topped to 100° *C.*

Date. 1929.	Specific Heat, cals./gm. ° C.	Mean Temperature, ° C.	Specific Gravity, 60° F./60° F
June 3 ..	0·4990 ..	43·3 ..	0·8374
	0·4995 ..	43·4 ..	
„ 5 ..	0·5149 ..	64·0 ..	0·8376
	0·5150 ..	63·9 ..	
„ 6 ..	0·4820 ..	24·9 ..	0·837
„ 10 ..	0·5357 ..	86·1 ..	0·8378
	0·5356 ..	86·1 ..	
„ 12 ..	0·5222 ..	15·0 ..	0·8374
„ 26 ..	0·5025 ..	18·6 ..	0·8378
	0·5007 ..	18·7 ..	
„ 27 ..	0·4822 ..	21·1 ..	0·8376
„ 28 ..	0·5428 ..	94·7 ..	0·8379

These results are plotted in Fig. 6.

10. General Discussion of the Results.

By the term "total heat" is meant the total energy content per unit mass of the substance measured from some arbitrary zero. All that can be measured in any calorimetric experiment is a change of total heat. If H_1 and H_2 are the total heats of the

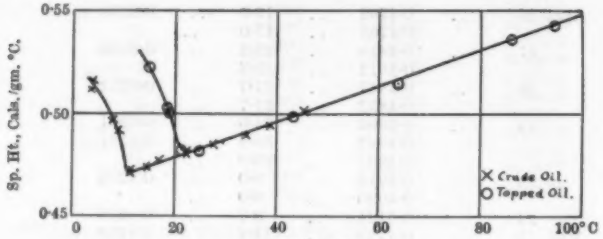


Fig. 6.

MID-CONTINENT OIL.

substance at the temperatures t_1 and t_2 respectively, then in order to raise the temperature from t_1 to t_2 at constant pressure a quantity of heat H_2-H_1 must be supplied. The measured specific heat is then given by the equation

$$s=(H_2-H_1)/(t_2-t_1)$$

and as (t_2-t_1) is never greater than 10° C. in these experiments the value of s so obtained cannot be greatly different from the theoretical value $(dH/dt)_p$, the differential of the total heat at constant pressure with respect to temperature. This definition takes into account the fact that some of the heat is necessary to cause the increase in the vibrational energy of the molecules, some in causing internal changes of the substance, besides that small part used in expanding the liquid against the constant external pressure.

With some of the oils used, below about 15° C. some wax or other solid molecules have already formed. At this part of the temperature scale more heat is required to raise the temperature 1° C., for it has to include the heat necessary to break up some of these molecular aggregates. As the temperature is lowered the number of these molecules present increases, the heat necessary to melt them increases, and so the specific heat of the liquid increases.

In the same way, as the boiling-point of the lightest constituents is approached, there will be a number of vapour molecules formed in solution. Near the boiling-point it is supposed that the number of vapour molecules formed per degree rise of temperature is

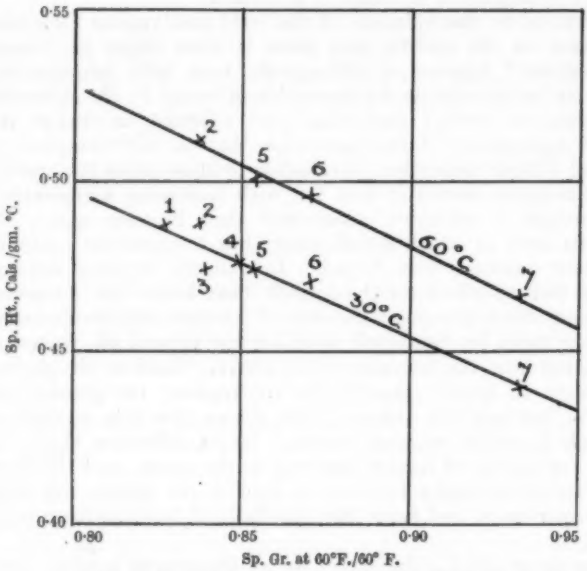
greater than the number formed at a point well removed from it. Thus it is to be expected that the specific heat curve here will be steeper, more especially if there is a large percentage of the lighter fractions. The rapid increase of the specific heat, near the initial boiling-point, is particularly important in the case of petroleum, as the presence of the heavier fractions prevents the actual boiling of the lighter fraction at the boiling-point of the pure hydrocarbon of which it is formed.

In addition to the influence of the solid and vapour molecules in solution on the specific heat there is what might be termed the "natural" increase of the specific heat with temperature, which may be regarded as the absorption of energy by the molecules themselves, as distinct from that part required to change the state of aggregation of the molecules, that is, the formation of solid and vapour molecules. According to these ideas the specific heat of a liquid should at first fall with increasing temperature, pass through a minimum value and then increase again. In those oils tried in which a sufficiently low temperature could be used these minima were found. In general, topping appears to have had no effect on the specific heat below the minimum value, and above this point the rate of increase with temperature was more rapid for the crude than for the topped oil, as would be expected from the reasoning given above. Further, the greater the change of specific gravity due to topping the greater the deviation between the curves. The reason for this is that in those oils in which topping makes a larger difference there is a greater percentage of lighter fractions in the crude, and therefore more vapour molecules have to be formed per degree rise than in the other cases, and hence the specific heat must increase more rapidly.

Above about 25° C., the curves for all the topped samples tried become straight, and the slope in each case is almost the same, the values being given in the detailed discussion below. At first sight, it would be expected that since the oil was topped to 100° C., as this temperature was approached, the specific heat would increase more rapidly than that given by a linear law, as it does for the crude oils. It has, however, to be remembered, that when the temperature of the vapour at the top of a long fractionating column is 100° C., the temperature of the residue in the still is considerably above this. So that, when, in these experiments, the residue, after topping to 100° C. was at a temperature of 100° C., it would still be some way off "boiling."

There seems to be a relation between the specific heat of the oil and its specific gravity. Thus at any given temperature the specific heat increases as the specific gravity decreases. To about

1 per cent. the relation is a linear one. The exact relation cannot be of a simple nature, however, because it has to account for the fact that at the lower temperatures the specific heat is the same for the topped oil as the crude although they differ in specific gravity. Two sets of values are plotted in Fig. 7 showing the specific heats at 60° and at 30° C. plotted on a specific gravity base.



1. *Mid-Continent, crude.*
2. *Mid-Continent, topped.*
3. *Pennsylvanian, crude.*
4. *Persian, crude.*
5. *Pennsylvanian, topped.*
6. *Persian, topped.*
7. *Californian, crude.*

FIG. 7.

SP. HEAT—SP. GRAVITY RELATION.

At the lower of these temperatures the matter is no doubt complicated by the rapid increase of specific heat of the crude oils as they approach their initial boiling point. Below the minimum points the influence of the wax causes a complete breakdown of any simple relation.

11. *Detailed Discussion of the Results.* (1) *Pennsylvanian Oil.*—Both the crude and the topped oil curves show a very definite

minimum at about 16° C., and the results for the two agree very closely below 20° C. This is all the more remarkable as different calorimeters were used and the experiments were performed by different observers. Above 25° C. the values were taken at intervals of 10° C. for the topped oil and were found to lie on a straight line to within 1 part in 500, which is the probable experimental error. The slope of this line is 0·0095 per 1° C.

(2) *Persian Oil.*—The deviation between the two curves above the minumum point is much more marked than in the case of the Pennsylvanian oil. In accordance with the theory given above, this is to be expected, as this oil contains a larger percentage of light fractions. One of the difficulties of experimenting with this crude oil was the continual loss of some of these light fractions in spite of all precautions to prevent this happening. During the series, the specific gravity of the crude oil increased from 0·8463 to 0·8508. This is largely due to the breathing of the tanks; each time one of the reservoirs is filled, the vapour in the space above the liquid is displaced and when the oil flows out again, air is sucked in again through the capillary port to replace it. There is thus a continual loss of the vapour of the lighter fractions. Now the effect of this loss can be judged from the effect of topping the oil. It is seen that below the minimum it is not going to have any influence, but as the initial boiling point is approached, the values would be slightly low. Thus the value at just over 30° C. found at the end of the series came a little over ½ per cent. lower than the value found at the beginning of the series. The minimum at about 18° C. is not so marked as for the other oils; the wax content is evidently less in this oil. Above 25° C. the values all lie on a straight line of which the slope is 0·00089 per 1° C., except those in the neighbourhood of 85° C. When this value came low, the experiment was twice repeated, and values agreeing to less than 1 part in 500 with the original value were obtained. Unfortunately, the apparatus then developed a leak, and it was not possible at the time to continue the experiments to a higher temperature, in order to ascertain if the curve does turn over towards 100° C. Below 15° C. no consistent results could be obtained, and after several attempts both with the crude and the topped oil, the experiments were abandoned; it appears that the state of the wax in this oil becomes unstable at these temperatures.

(3) *Californian Crude Oil.*—All the values obtained lie on a straight line the slope of which is 0·00095 per 1° C. As the initial boiling point for this oil was well above 100° C., it was not topped.

(4) *Mid-Continent Oil.*—With this light oil it was possible to perform experiments, with an initial temperature of 0° C., and the results even at this low temperature could be reproduced. It therefore appears that the state of the wax in this oil is more stable than in Persian oil. Two experiments at 11° C. performed on different days agreed to 1 part in 300, while two at 4° C. agreed to ½ per cent., which is as good as could be expected, for at these temperatures the experimental difficulties are greatly increased. The specific heat curve shows a sharp minimum, and has a peculiar shape. The specific heat falls linearly with temperature down to 11° C., and there is then a sudden increase until 9° C. is reached, and after this the specific heat continues to rise, but at a slower rate. The suggested explanation is that at about 10° C. a comparatively large amount of wax separates out, causing the rapid increase in specific heat, but below this temperature the wax comes out more slowly, and the slope of the curve is correspondingly less. It is interesting to note that this shape does not alter the general run of the total heat curve, which is the integral of the specific heat curve, and is of the same form for all the oils studied. It has to be borne in mind that a very small quantity of wax will cause a very large increase in specific heat, as the latent heat of wax is roughly a hundred times the specific heat of the oil. The specific gravity of the crude oil rose from 0·8240 to 0·8312 during the series of experiments, and this was due in the main to the breathing action of the tanks. As the experiments between 20° C. and 40° C. were taken at the beginning of the series before the change had become appreciable, it is not likely that the values obtained are in error by more than the other experimental errors. The experiment at 46° C. was made at the end of the series, and the result may therefore be slightly low.

The curve for the topped oil is precisely the same as that for the crude above 24° C., and has a similar peculiar shape below this point. It appears that in this case, however, the wax commences to come out at a higher temperature than in the crude, but it must be remembered that the topped sample was not initially identical with the crude, although it came from the same barrel, and it is therefore just possible that the wax content was slightly different in the two cases. The slope of the straight line part of the curve was found to be 0·00085 per 1° C.

12. *The Total Heat.*—By a graphical method of integration the total heat was obtained from the smoothed curve drawn through the values of the specific heat determined by experiment. The total heats were calculated in each case from the lowest temperature at which reliable results could be obtained, and a convenient

arbitrary value chosen at this point. It is important to note that the absolute value of the total heat cannot be given for it involves the intrinsic energy of the substance, and this is not known. The most usual quantity required is the amount of heat necessary to heat the substance from temperature t_1 to temperature t_2 at constant pressure, and this is the difference of the total heats at t_1 and t_2 and can be determined directly from the following tables. If, however, the mean specific heat over any range of temperature is required it may be obtained by dividing the difference of total heat by the temperature difference. On no account may the tables be extrapolated beyond the values given, for misleading results may be obtained. The fact that in some cases at the lower temperatures the crude and the topped oils have the same total heat has no special significance, it is solely due to the choice of initial values. The composition of the same crude oil varies slightly from one sample to another and for this reason the results obtained cannot be of practical value to the accuracy stated, they do however form a sound basis for comparison and discussion.

Units Used.—In the tables the total heats are given in calories per gram and the temperatures in degrees C. To convert the values to B.Th.U. per lb. they must be multiplied by 9/5, but no conversion factor is required to change to C.H.U. per lb. The specific heat has the same value in any consistent system of units.

TABLE IX.

Pennsylvanian Crude Oil.

°C.	0	1	2	3	4	5	6	7	8	9
10	5·000	5·474	5·946	6·416	6·884	7·352	7·818	8·284	8·750	9·216
20	9·683	10·151	10·619	11·087	11·556	12·026	12·496	12·967	13·439	13·911
30	14·385	14·860	15·336	15·814	16·293	16·772	17·254	17·737	18·221	18·706
40	19·192									

Persian Crude Oil.

°C.	0	1	2	3	4	5	6	7	8	9
20	10·000	10·464	10·928	11·394	11·860	12·328	12·897	13·368	13·840	14·314
30	14·789	15·266	15·745	16·226	16·708	17·194	17·680	18·169	18·661	

Persian Crude Oil Topped to 100° C.

°C.	0	1	2	3	4	5	6	7	8	9
20	10·000	10·464	10·928	11·493	11·859	12·326	12·794	13·261	13·729	14·198
30	14·668	15·138	15·610	16·082	16·554	17·028	17·503	17·978	18·454	18·930
40	19·408	19·886	20·365	20·845	21·326	21·808	22·290	22·774	23·268	23·754
50	24·240	24·727	25·215	25·704	26·193	26·684	27·176	27·668	28·161	28·655
60	29·150	29·646	30·143	30·640	31·139	31·638	32·138	32·639	33·141	33·644
70	34·148	34·653	35·159	35·666	36·174	36·683	37·192	37·702	38·213	38·726
80	39·239	39·753	40·268	40·784	41·302	41·820	42·340	42·860		

TABLE IX.—*continued.*

Pennsylvanian Crude Oil Topped to 100° C.

° C.	0	1	2	3	4	5	6	7	8	9
10	5·000	5·474	5·946	6·416	6·884	7·352	7·818	8·284	8·750	9·216
20	9·683	10·150	10·617	11·086	11·554	12·024	12·495	12·966	13·437	13·910
30	14·384	14·858	15·335	15·808	16·285	16·762	17·240	17·719	18·199	18·679
40	19·161	19·643	20·126	20·610	21·094	21·580	22·066	22·554	23·042	23·532
50	24·022	24·513	25·006	25·499	25·993	26·488	26·984	27·481	27·979	28·478
60	28·977	29·478	29·979	30·482	30·985	31·490	31·995	32·501	33·009	33·517
70	34·027	34·538	35·050	35·562	36·075	36·589	37·105	37·621	38·139	38·658
80	39·177	39·697	40·218	40·740	41·263	41·787	42·312	42·839	43·366	43·894
90	44·423	44·954	45·485	46·017	46·550	47·084	47·619	48·155	48·692	49·230

Californian Crude Oil.

° C.	0	1	2	3	4	5	6	7	8	9
30	15·000	15·441	15·883	16·326	16·769	17·213	17·658	18·104	18·551	18·999
40	19·448	19·897	20·347	20·798	21·250	21·703	22·156	22·611	23·067	23·523
50	23·980	24·439	24·899	25·360	25·821	26·284	26·747	27·212	27·677	28·143
60	28·610	29·079	29·548	30·018	30·489	30·960	31·433	31·906	32·380	32·856
70	33·333	33·810	34·289	34·768	35·249	35·731	36·213	36·396	37·180	37·665
80	38·151	38·638	39·126	39·615	40·105	40·595	41·087	41·579	42·073	42·567
90	43·063	43·559	44·057	44·555	45·055	45·555	46·056	46·558	47·061	47·565

Mid-Continent Crude Oil.

° C.	0	1	2	3	4	5	6	7	8	9
0	0·000	0·526	1·049	1·567	2·081	2·591	3·098	3·599	4·095	4·585
10	5·066	5·537	6·009	6·481	6·954	7·429	7·904	8·380	8·857	9·334
20	9·812	10·292	10·772	11·252	11·734	12·216	12·700	13·184	13·668	14·154
30	14·641	15·129	15·617	16·105	16·596	17·086	17·579	18·071	18·564	19·058
40	19·553	20·049	20·546	21·043	21·542	22·041	22·541	23·042	23·544	24·047
50	24·550									

Mid-Continent Crude Oil Topped to 100° C.

° C.	0	1	2	3	4	5	6	7	8	9
10						7·261	7·781	8·296	8·806	9·311
20	9·806	10·291	10·772	11·253	11·734	12·216	12·700	13·184	13·668	14·154
30	14·641	15·129	15·617	16·106	16·596	17·086	17·579	18·071	18·564	19·058
40	19·553	20·049	20·546	21·043	21·542	22·041	22·541	23·042	23·544	24·047
50	24·550	25·055	25·561	26·067	26·574	27·082	27·591	28·100	28·611	29·122
60	29·634	30·147	30·661	31·176	31·691	32·208	32·725	33·243	33·762	34·282
70	34·803	35·324	35·847	36·370	36·894	37·419	37·944	38·471	38·999	39·527
80	40·056	40·586	41·117	41·649	42·182	42·715	43·250	43·785	44·321	44·858
90	45·396	45·934	46·474	47·014	47·555	48·097	48·640	49·184	49·729	50·274
100	50·821									

13. *Comparison with the Work of other observers.*—It will serve no useful purpose to burden the paper with a lengthy discussion of other workers' results for the specific heat of petroleum oils, especially

TABLE X.

Oil.	Specific Gravity, 60° F./60° F.	Specific H						
		Observed.		Temp. Coefficient per ° C.	Lang's Equation.			
		30° C.	90° C.		30° C.	% Error.	90° C.	% Err
Californian Crude ..	0·9325	0·439	0·496	95×10^{-5}	0·438	—0·2	0·491	—1
Persian Topped ..	0·8694	0·470	0·522	89×10^{-5}	0·469	—0·2	0·522	0
Pennsylvanian Topped	0·8545	0·473	0·530	95×10^{-5}	0·476	+0·6	0·530	0
Persian Crude ..	0·8485	0·477			0·479	+0·4		
Pennsylvanian Crude .	0·8395	0·474			0·483	+1·8		
Mid-Continent Topped	0·8375	0·487	0·538	85×10^{-5}	0·484	—0·6	0·537	—0
Mid-Continent Crude .	0·8275	0·487			0·487	0		

TABLE X.

Specific Heat in							
Observed.		Temp. Co-efficient per ° C.	Lang's Equation.				
° C.	90° C.		30° C.	% Error.	90° C.	% Error.	30°
439	0·496	95 × 10^{-5}	0·438	—0·2	0·491	—1·0	0·4
470	0·522	89 × 10^{-5}	0·469	—0·2	0·522	0	0·4
473	0·530	95 × 10^{-5}	0·476	+0·6	0·530	0	0·4
477			0·479	+0·4			0·4
474			0·483	+1·8			0·4
487	0·538	85 × 10^{-5}	0·484	—0·6	0·537	—0·2	0·4
487			0·487	0			0·4

pecific Heat in cals./grm. ° C.

ation.		Fortsch and Whitman.				Cragoe's Equation.			
° C.	% Error.	30° C.	% Error.	90° C.	% Error.	30° C.	% Error.	90° C.	% Error.
491	—1·0	0·435	—0·9	0·499	+0·6	0·441	+0·4	0·486	—2·0
522	0	0·458	—2·5	0·522	0	0·457	—2·7	0·504	—3·6
530	0	0·464	—1·9	0·532	+0·4	0·463	—2·2	0·509	—4·2
		0·466	—2·3			0·462	—3·2		
		0·469	—1·0			0·464	—2·2		
537	—0·2	0·470	—3·5	0·535	—0·6	0·466	—4·2	0·513	—5·0
		0·474	—2·7			0·468	—4·0		

as this has already been done by Fortsch and Whitman[1] and others, and more recently with great thoroughness by Cragoe.[2] Some general remarks may, however, prove of interest. Most observers have contented themselves with a low order of accuracy about 5—10 per cent., and have fitted an equation, containing the specific gravity and the temperature, to their results. Now a change of only 25° C. or only 0·05 in specific gravity will bring about a change of about 5 per cent. in the specific heat. It is important then, first to obtain results accurate to at least 0·5 per cent. before any attempt can justifiably be made to investigate the random discrepancies from such an equation.

The formulæ published by Fortsch and Whitman, and by Cragoe, (loc. cit.) fit the present results fairly well, but the main objection to them is that the temperature coefficient is dependent on the specific gravity. Neither the published data nor the present results seem to warrant this. We have therefore thought it best to take a constant coefficient, and have accordingly fitted the following equation to our results above the minimum value.

$$dH/dt = s = 0{\cdot}00090t - 0{\cdot}499 \text{ (sp. gr.)} + 0{\cdot}856.$$

where s is the specific heat at a point in calories per grm. °C. and t is the temperature in degrees C., while the specific gravity is, as the common practice given at 60° F. in terms of water at 60° F. The comparison of fit of the various formulæ when applied to our results is given in the Table X.

It will be observed that Cragoe's formula gives values considerably too low, while that of Fortsch and Whitman is in fairly good agreement. The formula given above fits extremely well. This formula also closely fits other results (*e.g.*, those of Henderson, Ferrai, and McIlvain[3]) at temperatures below 100° C., but yields values a few per cent. too low if extrapolated much above this point. This is because the temperature coefficient has been chosen to fit the present series of results and is too low to cover a wide range of temperature.

It has been repeatedly pointed out by other writers, and the present work confirms this, that these formulæ can at best be only approximations, and as already stated, the true relation cannot be of a simple nature because it must account for the fact that the crude and the topped oils have the same specific heat at the lower temperatures although they differ in specific gravity.

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[1] *J. Ind. Eng. Chem.*, 1926, **18**, 795.
[2] Misc. Publications Bureau of Standards No. 97, 1929.
[3] *J. Ind. Eng. Chem.*, 1929, Analytical Sect., **1**, 148.

Some rough experiments were made on crude oils by Mabery and Goldstein[4] over the range 0° C. to 50° C., using a Bunsen's Ice calorimeter and their results must have been influenced by the presence of wax, and this is borne out by the fact that the values for the crudes most likely to contain wax are consistently high compared with the value calculated from Lang's formula.

Wales[5] has made some measurements on Californian crudes which are on the whole in good agreement with the present values. He also observed that when there was a large percentage of light fractions present, the specific heat at 20° C. was about 10 per cent. greater, which is exactly in accord with our results.

14. *Acknowledgments.*—We wish to express our feeling of obligation to the late Professor H. L. Callendar for placing every possible facility at our disposal for the work, and for much helpful advice. We are also indebted to Messrs. A. M. Thornton and W. L. Watton, for assistance in taking the observations, and to Mr. W. J. Colebrook for helping in the design and construction of the apparatus.

Note added April 30th, 1930.—By the courtesy of Messrs. Shell-Mex Ltd., more detailed analyses of the samples used are being carried out in their central laboratory, and a further discussion of the present results in the light of these analyses will subsequently be given.

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[4] *Proc. Amer. Acad. Sci.*, 1902, **37**, 539.

[5] *J. Ind. Eng. Chem.*, 1914, **6**, 727.

The Connection Between the I.P.T. Gravity Temperature Correction Constants and the Coefficient of Expansion of Petroleum Oils.*

By I. A. J. Duff.

It is noticeable that there is a lack of general knowledge as to the correct coefficient of expansion of petroleum products and that in many instances it has been assumed that the I.P.T. figure for gravity temperature correction can also be used as a volumetric expansion coefficient. The real figure is obtained by dividing the sp. gr. temperature correction figure by the sp. gr. and changing the sign as will be seen from the mathematical appendix.

As a single instance of the errors involved, the writer notes that many quote the expansion figure of spirit as four in ten thousand per degree Fahrenheit, whereas theory and practice both find a coefficient of expansion of 6·5 in ten thousand per degree.

Let δ, v, w be sp. gr. $\left(\frac{60^\circ \text{ F.}}{60^\circ \text{ F.}}\right)$, volume and weight of the product at 60° F.

and δ_θ, v_θ, w be the sp. gr. $\left\{\frac{(60 \pm \theta)^\circ \text{ F.}}{60^\circ \text{ F.}}\right\}$, volume, and weight of the product at $(60 \pm \theta)^\circ$ F.

Let C be the coefficient of volume increase and K the coefficient of I.P.T. gravity temperature correction.

Then δ, v, w are inter-related so that $w = \phi \delta v$ where ϕ is a multiplying constant different for each set of units.

(If w is in lbs., v in gallons, $\phi = 10$.)

$$w \text{ also} = \phi\, v_\theta\, \delta_\theta$$

$$\text{now } v_\theta = v(1 + C\theta) \text{ approx.,}$$

$$\text{and } \delta_\theta = \delta + K\theta$$

$$\phi\, v_\theta\, \delta_\theta = w = \phi\, v\, \delta$$

$$(1 + C\theta)\, v\, (\delta + K\theta) = v\, \delta$$

$$1 + C\theta = \frac{\delta}{\delta + K\theta}$$

$$= \frac{1}{1 + \frac{K}{\delta}\theta}$$

* Paper received February 10, 1930.

As $\frac{K\theta}{\delta}$ (for small values of θ) is quite small the right-hand side can be expanded binomially and squares and upwards neglected.

$$1 + C\theta = 1 - \frac{K}{\delta}\theta + \frac{K^2}{\delta^2}\theta^2 \ldots\ldots$$

$$\text{or } C\theta = -\frac{K}{\delta}\theta$$

$$C = -\frac{K}{\delta}$$

i.e., C varies inversely as δ, which has been established for most oils.

It must be noticed that v_θ, which equals $v(1 + C\theta)$, is greater than v when θ is positive (for temperatures above 60° F.) and smaller than v when θ is negative (for temperatures below 60° F.), and that δ_θ, which equals $\delta + K\theta$, is smaller than δ when θ is positive, and larger than δ when θ is negative, since K is a coefficient of permanently negative sign (C is always positive since all known petroleum products expand on heating and therefore K must be permanently negative).

A few figures are tabulated acknowledging K figures as derived from "*Standard Methods of Testing Petroleum and Its Products.*"

	K (value at 60° F.).	δ	C (value at 60° F.).
Spirit below 0·740	0·00048	0·735	0·00065
,, above 0·740	0·00044	0·741	0·0006
White Spirit	0·00042	0·781	0·00054
Kerosines	0·00040	0·795	0·0005
Vaporising Oil	0·00039	0·827	0·00047
Gas Oils	0·00036	0·860	0·00042
		0·871	0·00041
Diesel	0·00035	0·895	0·00039

REVIEWS.

DIE KRACKVERFAHREN UNTER ANWENDUNG VON DRUCK (DRUCKWARMESPALTUNG). Dr. E. Sedlaczek. Pp. iv + 402. Berlin, J. Springer, 1929. 45rm.

This very excellent review, typically Teutonic in the thoroughness of its treatment, is entirely necessary to the petroleum technologist.

The first part handles both the better and lesser known patented processes, such as those associated with the names of Cross, Burton, Dubbs, Jenkins, Ellis, Isom, Ramage, and McAfee. Excellent line drawings accompany the text.

In the second part the classification of cracking into groups of processes is dealt with, for example, the category of heating by fused metal baths and for the employment of a variety of catalytic methods. Curiously enough the more modern high-temperature processes do not receive the attention they deserve in view of to-day's urgent need for high anti-knock material.

In the reviewer's opinion it is an appropriate time to abolish the ludicrous expressions "liquid phase" and "vapor phase" cracking. Many of the former processes function with the material in the critical state. Better would be the terminology "high-temperature" and "low-temperature" cracking.

The discussion of the refining problems incidental to cracked spirit is the least satisfactory part, and should be extended in the next edition.

Finally, emphasis should be laid on the indispensability of the book, its excellent get up, and first class index. A. E. DUNSTAN.

THE PROBLEM OF OIL. Christopher T. Brunner, M.A. London, Ernest Benn, Ltd., 1930. 15s. net.

Mr. Brunner is to be congratulated on writing a useful and timely book dealing largely with matters which, although some of them form the subject of frequent discussion in the oil journals, have not been brought together hitherto in a well-written treatise such as the present. These are days when one can hardly pick up a newspaper without coming across references to economic subjects. Governments appoint Committees of "Economic Advisers" and arrange Economic Conferences. It is recognised more and more that the principles of the once despised "dismal science" of economics lie at the root of sound business, and must be taken into account in technical, scientific and commercial organisation. Commercial and technical men alike recognise the value of an acquaintance with economic theory. Mr. Brunner's book should incidentally find a place in the curriculum of students of Petroleum Technology. But business men in the oil industry will also find his book of interest, particularly because he supplies so much detailed knowledge and so many facts and data of the uses and economic position of the various products of the oil industry, and shows how oil touches at so many points the whole economic life of the nation:—How fuel oil competes with coal for steam raising and house warming; how the Diesel engine may sooner or later be a competitor, in heavy vehicles at least, with the present automobile type of engine; how benzole, a coal product, or power alcohol, a vegetable product, may be used blended with petrol; what may be the "saturation point" of the number of motor vehicles; what will happen to gas oil and kerosine; into how many industries, from metal polishes to

linoleum, "white spirit" enters; what is doing in extracting oil from coal and shale; how stand the values and uses of lubricants; how far the Diesel will supplant steam raising in ships or what effect on type and quantity of fuel other marine-engineering developments may produce; whether tar, a British product, can partly meet national needs as a road-surface material in competition with imported bitumen; whether agriculture can be saved by ploughs and other mechanisms, petrol or kerosine driven; these and a hundred other details of development must be watched by the leaders of the oil industry and their assistants whose duty it is to vary production at the wells, operations at the refineries, and stocks at the distributing centres to meet changes of demand in quantity and descriptions of many products. It is hardly necessary to do more than allude to the world-wide ramification of the oil industry with oil fields not always situated near to the large centres of requirement. Here let us emphasise that no amount of economic theory and not all the professors of the world's universities, nor accumulated data and facts can save or build up a business by themselves. This depends on the use made of theory and data by men of business—judgment, experience, foresight and enterprise. Particularly this is the case in times of trade boom or depression. The business man rather than the economist must form his judgment how long the boom will last, how far its effects will be permanent, and as to the factories, plant, ships, etc., that must be built to meet that need without excess and waste? In times of depression, the questions to be determined are how to plumb the depths and to look around to see what "rationalisation" and reduction of overhead charges, etc., can do to help? Or if "over-production" is the fault, what amount of "conservation or restriction" may be feasible to avoid excess supplies in the market without running to the opposite extreme of monopoly? Mr. Brunner shows that all these large matters, besides the many details as to the several products, must be faced by the leaders of the industry. There are also the ever-present questions of putting down new wells with the attendant increased costs of drilling to greater depths. Mr. Brunner reassures the public against any fear of monopoly prices. Apart from "long" views of the bigger concerns in the industry there are the potent agencies of present over-production and the competition of many small producers. Also there is always the menacing finger of the actual or potential competing "substitute."

In a recently broadcasted address Lord Hewart, Lord Chief Justice, spoke of the difficulty of putting general moral precepts into an Act of Parliament. Similarly a statute imposing penalties for short supplies (but without compensation for losses on supplies in excess of requirements) would, of course, hardly be feasible. For this and other reasons such expressions as the "law of supply and demand" or "iron and inexorable economic *laws*" are often objected to. The good citizen has no fear of penalties for theft or violence, but the best efforts of the good merchant or manufacturer cannot always control natural causes affecting supplies of commodities. Nevertheless the penalties to the producer of low prices for excess supplies and to the consumer of high prices in the case of shortages are very real in their effects. The wise economist of to-day, disregarding the old theories of "cut-throat" competition forcing profit and wages to a minimum, counsels always the golden mean.

We commend Mr. Brunner's book generally. His chapter on "Economics of Oil" is particularly good. In his advocacy of imported bitumen against British tar for road-making Mr. Brunner, whether sound or not on the material issue, loses for a moment his usual judicial calm. Otherwise his descriptions of the merits of various products and their uses as well as of the competing distribution organisations, seem to us on the whole to be well-informed and

unbiased. Considering the technicalities of such matters his pages are interesting and readable. His remarks on "rationalisation" (of which he gives a good definition—page 213) and "conservation of oil" and "co-operation between oil groups" appear also to be sound and timely.

F. W. BLACK.

UNTERSUCHUNGSMETHODEN DER ERDÖLINDUSTRIE. Dr. H. BURSTIN, Berlin. Julius Springer, 1930, pp. xii. + 300, with 86 figs., 24 r.m.

The author's object in writing this book of some three hundred pages is to present the methods of analysis (both routine and research) and examination of petroleum products, in a condensed form. In the writer's opinion, however, it is impossible to deal satisfactorily with a subject of such size and importance in so small a book.

Dr. Burstin has sought to combine the essence of the well-known work of Holde and some, but not all, of the A.S.T.M. and I.P.T. methods of testing, with other little-known tests whose value has certainly not been proved. It is surprising to find that many of the proven American and British standard tests have not been mentioned, and that there is an inexcusable omission of a description of the determination of calorific value.

Many of the tests described are wanting in those details of operation which are so necessary for the accuracy of the tests and their manipulation. One example of this is the description of burning tests for kerosines. Although the author covers himself by saying that every different type of oil requires a lamp suitable for its characteristics, he quotes only two types of lamp both of the circular wick type, and ignores for example the standard A.S.T.M. testing lamp, which utilises a flat wick. He does not mention the fact that a flat wick burner shows differences in burning qualities very much better than does one of the circular wick type. The details for carrying out burning tests are very meagre, and not very helpful when one considers the extreme care which has to be exercised in order to obtain comparable results.

Owing to the division of the subject matter into two parts, namely general methods and special methods, there is a considerable degree of repetition which might have been avoided by a different arrangement of the tests.

A small bibliography of "useful literature" is given at the end of the book, but even this might, with advantage, have been expanded.

On the whole, therefore, the book cannot be recommended as a very useful addition to the library of the petroleum technologist. W. H. THOMAS.

PETROLEUM VADEMECUM. R. Schwarz. VII. Edn., in 2 vols. Pp. 224 and 329. Berlin and Vienna, Verlag für Fachliteratur G.m.b.H., 1930, 24s.

This handbook of international petroleum tables has now reached its seventh edition, and for the first time is published in two volumes.

The whole work is divided into three parts, the first two being contained in Volume I. Part 1 deals with Chemical and Physical Tables for the petroleum industry and contains conversion tables for weights and measures, specific gravity in various units and at varying temperatures, viscosity, and miscellaneous data. Part 2 gives details of the tariff duties on mineral oils in different countries. Part 3 is the statistical section, and gives details of production, imports and exports of petroleum and its products for various countries. Included in Volume II. is an orientative map of the World's Oil Industry, on which is marked the localities where various operations are, or have been, carried out.

As in the previous editions, the subject matter is written, as far as possible, in German, English and French, and this arrangement adds to the value of what is a useful reference work. G. SELL.

CHEMICAL ENGINEERING AND CHEMICAL CATALOGUE. Edited by D. M. Newitt. London, Leonard Hill, Ltd., 1930. Pp. lviii. + 393. 15s.

The sixth edition of this annual reference book shows a considerable improvement and enlargement on its predecessors. All the sections have been revised and brought up-to-date, and the Data and Tables Section in particular has been practically doubled, including many specially compiled tables.

An interesting and useful innovation is the setting of the main index, the key to the whole work, in Spanish as well as in English, and this greatly increases its usefulness to those having dealings with the Spanish-speaking South American countries.

As a link between chemical practice and theory, apart from its value as a work of ready reference, the book should prove a useful addition to the library of anyone engaged in the chemical industry. G. SELL.

BOOKS RECEIVED.

THE ASSAY OF COAL FOR CARBONISATION PURPOSES. Part III. J. G. King and L. J. Edgcombe. London: H.M. Stationery Office, 1930. Pp. vi. + 30, with 6 figs. and 1 plate. 9d. net, postage extra.

This paper, Fuel Research Technical Paper No. 24, is the third of the series dealing with the assay of coal for carbonisation purposes, and deals with a modification of the assay apparatus to make it suitable for testing coals to be used in gas retorts.

THE MICROSCOPICAL EXAMINATION OF COAL. C. A. Seyler. London: H.M. Stationery Office, 1930. Pp. vi. + 67, with 83 figs. 2s. 6d. net. postage extra.

This is Paper No. 16 of the series on the Physical and Chemical Survey of the National Coal Resources, and records some of the results of Mr. Seyler's work during the past few years. The report is chiefly concerned with the methods of, and results obtained by, polishing and etching flat surfaces of coal. Plant structures are shown to be more numerous than previously supposed, and the method used allows of sections being prepared in three determined planes meeting at right angles in a selected part of a plant fragment.

A description is also given of simple photomicrographic apparatus, with working details, and the technical work is followed by an account of the cell structures found in coal.

REPORT OF TEST BY THE DIRECTOR OF FUEL RESEARCH ON THE TURNER RETORT INSTALLED AT THE WORKS OF THE COMAC OIL CO. LTD., COALBURN, LANARKSHIRE. London: H.M. Stationery Office, 1930. Pp.

This retort is of the vertical, continuous, internally heated type, heating being carried out by superheated low-pressure steam injected into the base. A vapour outlet at the top remains closed until the steam has raised the pressure in the retort to a desired maximum, and then instantly opens until the pressure drops to a desired minimum, when it closes.